THE CHEMISTRY OF COMMERCE

ROBERT KENNEDY
DUNCAN

David Wells Conrey-

Dec. 25 - 1907.

Δ-G.P.
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So very, very true, and so very very pretty.
Just as pictured.

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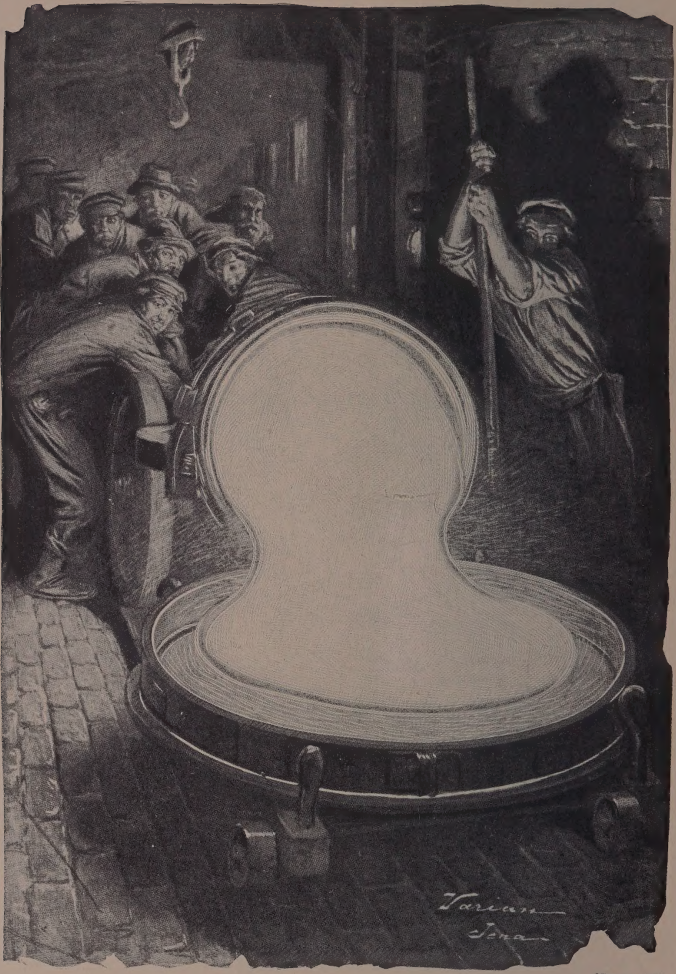

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CASTING A GREAT LENS AT JENA. THE CRITICAL POINT

THE CHEMISTRY OF COMMERCE

A SIMPLE INTERPRETATION OF SOME NEW CHEMISTRY IN ITS RELATION TO MODERN INDUSTRY

BY

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"THE NEW KNOWLEDGE"

ILLUSTRATED

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TO

MY WIFE

WHO SO BRAVELY TRAVELLED WITH ME THE
MANY JOURNEYS THAT WENT TO THE
MAKING OF IT, THIS BOOK IS
LOVINGLY DEDICATED

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PREFACE

THIS book is a straightforward attempt to interpret into simple terms and for educated lay-folk some new science in its relation to modern industry. But the interpretation of science is by no means easy; it is one of the most difficult of arts.

Certainly, the discoverer of any new work is himself almost inevitably incapable of telling it; and it results, generally, that a world of educated laymen, intellectually eager to know of the advance of knowledge, subsist on a pabulum of illogical and, for the most part, sensational misinformation; either that, or discoverer and discovery together remain unknown to 99.99 per cent. of educated people. The extreme difficulty of the art is the real reason why it is either not practised, or practised in such a way as to appear discreditable in the eyes of men of science. It is not by any means that the art is not needed among men. The thousands of young men that go out of the schools into business and professional life are not fools, nor do they desire the stagnation of the intellectual curiosity that has been stimulated in them; men eagerly desire to know the significant results of modern knowledge.

In view of these difficulties of the art of interpretation, the writer of this book cannot pretend to have succeeded completely; with a knowledge of the difficulties of the art, he has incidentally proved the corollary of his own limitations. But he has done his best; and he has tried because through another book he has written he has received words of appreciation so sincere, and from sources so far apart in station and in location—from mining engineers in South Africa to school-teachers in China and from captains of the navy to captains of industry—that it has been borne in upon him that, failing other voices, it is his to practice, as a part of the day's work, the humble and difficult art of singing the deeds of other men.

While in this book there does not inhere the romantic interest attached to radioactivity and the nature of the chemists' atom, it possesses the glorious interest that attaches to the doing of real things. If through the reading of these pages any man engaged in the making of things sees once and for all clearly as in a crystal the absolute applicability of science to his industry, and if any young man at the threshold of his activity is led thereby to perceive that the application of science to the material needs of men is just as much science and just as much research as that which is pursued solely for its own ends, the writer will be satisfied. It will be so much, however little, towards a realization of the writer's intense conviction that only through the application of modern science to industry will there ever come into the world an era of gracious living.

R. K. D.

University of Kansas
Lawrence, May 16, 1907.

THE CHEMISTRY OF COMMERCE

THE CHEMISTRY OF COMMERCE

I

INTRODUCTORY

ONE object of this book is to convince the manufacturer, through instances taken here and there, how absolutely applicable is modern science to the economy and progress of manufacturing operations. It seems passing strange that such a thesis should need demonstration, but it is no more strange than true. To the informed, the condition of much of American manufacture, and, doubtless, English, too, is a chaos of confusion and waste; and this despite the large volume of the manufacture and the profits that have attended its practice.

In our country, astonishing to say, success in many cases has been achieved actually by working in accordance with the motto, "Save at the spigot and waste at the bung." By this I mean that in some manufactures the competitors, through ignorance of the possibilities of modern knowledge, have equally conducted their factories along the lines of prejudice and tradition, and that the deciding factor in competition has lain not in factory economies and progress, but in expert office management. The office management has been concerned, first of all, with business, *i. e.*, the making of money, and only secondly—and often distantly at that—with the true manufacturing function, which consists in making the best thing at the cheapest price.

Some paint manufacturers, for example, have been concerned not in standing proudly as the makers of the best paints in America, but in paying large dividends. When in any industry manipulators take over the manufacturing function, pecuniary success, the measure of value, rests upon conditions far other than manufacturing efficiency. In my opinion many exploiters of industry have evolved through the era of "protection"; and by protection they have been enabled, for the elimination of competition, to construct combinations of such a character that for the purpose of money-making, efficiency in manufacture has become subordinate to this efficiency of exclusive control obtained through business intrigue.

Concomitantly with the evolution of these huge combinations for the maintenance of artificial prices, there has developed another of huge and lying advertisement, and still another of the gross adulteration of manufactured products. These three methods of exploiting industry are simply and essentially three methods of getting rid of the efficiency in manufacturing operations by which every business should naturally stand or fall. But the fact is that all these factors are in rapid process of elimination, and there remains, or will shortly remain, as the one dominant factor of industrial success, just simple efficiency, by which I mean a combination of economy and progress in factory practice.

Consider this business of lying advertisement: It is a highly developed art, but it is one that it becomes daily more difficult to render specious. This is partly due to the exposure of many self-lauded articles, but more particularly to the educated sense of the people, who are no longer content to accept mere *vraisemblance* as a test for truth. To such an extent is this true that manufacturers have actually begun to advertise the plain truth.

Then there is the enormous business of fraudulent adulterations. It is safe to say that the framers of the Pure Food and Drug Law had but a small appreciation of how apposite it was to the sentiment of the people, and how stringently it would be enforced, and how widely its provisions would be copied and amended and extended by the individual States. The makers of fraudulent material are in parlous case, not merely in instances such as are covered by the law, but in all. The sentiment of the people, awakened by knowledge, is so strong and obviously so enduring that such men are daily being forced for their own salvation either into honesty and efficiency or into an actual abandonment of their business.

The combinations of capital that have been operating in restraint of trade are in similar case. The Federal laws, supplemented by the laws of the individual States, are formidable in what they stand for, and the attitude of the people is menacing in its settled determination that these laws shall be enforced, and that they shall be supplemented by others that shall, as much as is practicable, eliminate the whole process of unethical business. For this and succeeding generations the days of *laissez-faire* are past, and ever more and more the combinations of capital will be forced back upon the basis of their original excuse for existence, the efficiency which may result from large-scale operations.

Every man, in the future, in order to succeed, will find it more important than any other consideration to conduct his manufacture *secundum artem*. But the practice of any manufacture *secundum artem* has a meaning wholly different from that of other days. It does not mean practising the art through the best tradition; it means pursuing the art with the aid of modern knowledge. Wholly different from manufacture in the days of our fathers, its necessary conditions are not static, but dynamic. The industrial struggle which is about to be precipitated in America will be fought out on a basis of efficiency, better efficiency, still better efficiency, but, universally, efficiency.

Wise men who make things already understand this, but they do not know or they know only in part how much chemistry has to say as to what constitutes this efficiency. But if the reader will consider this, he will presently perceive that since every manufacture deals with substance, and substance is the business of chemistry, every manufacture is, just to that extent, chemical. Does the reader make something, does he wish to make it cheaper, does he wish to make it better, does he wish to utilize its by-products, does he wish to transform it into something still more valuable, then he will find in modern chemistry, for the most part, his one way to these ends. What a touchstone chemistry is to efficiency, how it may extract strength from weakness, how it may transform waste into saving, how it may transmute by-products into gold, may all readily be seen in succeeding pages. The instances therein, taken here and there from the progress of scientific industry, are amply confirmative of the proposition that into every factory there should go a laboratory. But the laboratory will need a chemist, and this naturally brings me to the second object of this little book.

I earnestly desire, through succeeding pages, to show the young man adequately trained in chemical science, but on the threshold of his activity, what enormous opportunities for service to man, for advancing knowledge, and for material reward lie waiting perdu in the practice of Industrial Chemistry.

But before speaking of these opportunities, there is a consideration that gives us pause. This consideration has to do with the ideals of scientific achievement. The student in college is currently and traditionally taught that Science should be served for her own sake, that causing her to subserve utilitarian needs sullies her beauty, and that obtaining material rewards through her degrades her devotee. Let us foregather with this question. Its answer depends on how we answer a question of a wider scope: Why do men work? Many good men imagine that they work for money, but they deceive themselves. No good man works for money, or power, or fame, or any other specific object, even the advancement of knowledge. He works at a thing because it is for him the thing to do; he works subconsciously and almost automatically to develop the highest expression of his most efficient powers. But the young man no sooner sets about this man's business of expressing himself than he finds that he must do so through necessities and responsibilities. Now, in this diverse world, the powers of man and the forms of necessity and responsibility are also diverse. Through the values he ascribes to all these entities, and through their give and take, the reaction of the man's life takes place. How the result of this reaction should be measured is little of our concern, and, perhaps, not much of his. If it is actual and sincere, and the expression of the man's best working, it is worthy a perfect mark.

Let us see how this works out. It means that to a young man who is the recipient of a modern scientific culture, ideals of scientific achievement give way to the ideal of his own achievement. This habit of personifying science is mischievous; it leads to the establishment of a cult. Science is a body of knowledge existing for man, and it is the result of an ideal of achievement in man that finds expression in the phrase *Sincerity for truth.* Knowledge obtained through this ideal is equally science, whether it is significant only to thought or whether it subserves practical ends. The doing of the thing in accordance with this ideal is the glory thereof, for it is thus that man finds the completest expression of himself. If, for example, a man finds himself hindered in this self-expression by a yoke of pecuniary necessity, he is just as dignified in freeing himself of it through the accomplishment of utilitarian research, as is another dignified in preferring to remain with his neck therein, who drags a wife and family through a life of penury in order to carry out a research that has no present-day significance.

And the world needs both. Of course there is no disposition in this book to belittle the work and the workers in "pure" science. The achievements of "pure" science in one generation constitute the formulæ of the "applied" science of the next, and outside altogether of material application they have their absolute justification. But in our day the preferred work of the world is the doing of real things, *i. e.*, things having significance to human needs, whether material or concerning thought or conduct. Even to-day the manufacturers of this country have so far awakened to the need of efficiency that the universities can barely supply the demands for adequately trained men, and yet the process of this industrial transformation has only just begun. In no field of human effort do there exist such opportunities for genuine achievement as shall exist in the next twenty years in Industrial Chemistry.

But to any young man proposing to enter this field, perhaps a word of advice should be spoken. After having formed such a determination, let him forget it. Throughout the five or six years of his chemical nonage, it should be his one business to learn all the chemistry and cognate knowledge that he can lay his hands upon in the laboratory, and his brain alongside of in the study library, and this without any thought whatever of its possible industrial application. Only thus can he hope to arrive at real achievement in after-industrial research, and only thus can he stand with self-respect beside his fellow-researchers in "pure" science. In his training, in his methods, and in his work he should be a chemist—a *real* chemist, and only in the outcome of his work a technologist. With hands trained to accomplish what his will directs, and with an adequate store of chemical knowledge to inspire his will, he can then command achievement to the extent of the man that is in him.

For the manufacturer through whom such a man works there is also a word of advice: Let him not expect immediate results. Let him, rather, leave the man to brood two years, three years, or even five years, over his work, for experience has shown that such patience is regularly and munificently rewarded. Having made sure of his man (and in that, of course, lies the supreme difficulty), it is for the manufacturer to refrain from burdening that man with routine duties, such as may be fulfilled by laboratory boys; it is for the manufacturer to give him adequate laboratory facilities, and at the very initiation of his work to give him plainly to understand that while he must not interfere with factory operations except through previous demonstration and on a basis of practical reason, and while he must not antagonize the men, the factory is his, and the responsibility for what he does in it and to it.

But what about the fruits of toil? Though no good man works for money, he has a right to demand the money worth of his work. In Chapter XII. of this book I have outlined what seems a sane and practical scheme of relationship between the manufacturer and the industrial researcher. For the researcher who is *within* the factory a similar arrangement seems reasonable—a living wage, *i. e.*, a wage sufficient to free him from the paralyzing effects of pecuniary embarrassment and ten per cent. of what he accomplishes, whether in saving or in progress.

Though every good man works to develop to their most efficient practice the special aptitudes he deems himself to possess, there is generally in "the back of the head" of such a man an earnest desire that such aptitudes should be exercised for the good of his fellows—generally, not always. I remember a brilliant young researcher who told me that he had developed a wholly new chapter in mathematics. "And the best of it is," he said, with a glow of enthusiasm, "that it can be of no earthly use, either practical or theoretical"! How pitifully futile was that work when one thinks of the needs of men, and what that same enthusiasm and that same ability might have wrought towards their fulfilment. Had that man passed observingly through the vicious purlieus of the Bowery, or through the vast, sordid stretches of East London, surely it would have struck home to him that his work was not only not right, that it was a crime.

Since everywhere through modern science there exists knowledge applicable to the needs of men, no man of science can justifiably make of himself an anchorite. The doing of real things is the preferred work of the world. Preachers, publicists, law-makers, and lawsustainers, whether they be soldiers, judges, or pleaders, may do their utmost for the world's uplift, but their efforts can be but of little and temporary avail until the material conditions of men are ameliorated. So long as men must live sordidly to win the means of satisfying even their sordid necessities, so long will there exist the vulpinist in man. Man can really live only when he has the chance to live, and this chance to live depends upon shortening for him the hours of his necessary toil, and upon throwing easily within his means the obtainment of the amenities of life.

There is but one way of lifting man to a higher moral and spiritual plane, and that is by lifting to a higher plane the conditions of his material surroundings; and the one sole way of accomplishing this is through the application of knowledge to the making of the things he needs. Any man who makes a new thing, a better thing, or a thing in a better way, does in that act a good that will never pass away. Even to-day it is doubtless true that if efficiency, and only efficiency, counted in the price of the products for man's needs, no worthy man would need to go hungry nor any naked; but in the future, when up to it, through every year, if the efficiency of his work increasingly grows through the application of new knowledge, there will result not only the satisfaction of the hunger of his body, but an opportunity to satisfy the hunger of his soul. And we shall have better men, not only because of this, but because efficiency in work means efficiency in workers; and the insistency upon efficiency is an eliminating factor of high evolutionary importance.

The efficiency—of control, of action, and of result—that marks the operations of science is the saving word to all the lives and works of man. To strive to tell all this through a few salient examples, why, speed thee, little book!

II

CATALYSIS: HOW A PHENOMENON, RECOGNIZED ANEW, MAY AFFECT MANY INDUSTRIES

IN a certain very old book ascribed to Ramundus Lullus, Doctor Illuminatissimus, there is contained the account of a remarkable substance. "Take of this precious medicine," he says, "a piece as large as a bean. Throw it upon a thousand ounces of mercury, and this will be changed into a red powder. Place one ounce of this latter upon one thousand ounces of mercury, which will thereby be transformed into a red powder; of this again, an ounce thrown upon a thousand ounces of mercury will convert it entirely into medicine . . . of this last medicine, throw once more an ounce upon a thousand ounces of mercury, and this will be entirely changed into gold which is better than gold from the mines."

Concerning the actual existence of this transcendental medicine, it must be confessed that the Illuminated Doctor was either dreaming or scheming, though the essence of our incredulity lies, possibly, in our reluctance to admit that this "medicine" could act by its mere presence, by merely being there, and in a quantity so infinitely small. The commonly received idea of chemical action, as thousands of young men and women are learning it in the schools, forbids all this. They are taught that chemical action takes place *between* substances. Thus, a common type of chemical action is a case of "trade." To take a non-chemical example: An Italian peanut-vender and his peanuts are a fairly stable compound; so is a boy with a penny so long as the compound is isolated. But place the compounds together, and the following reaction immediately takes place:

Peanut-vender . peanuts + Boy . penny = Peanut-vender . penny + Boy . peanuts.

Other chemical actions may be classified as a highway robbery, or marriage, or divorce, or what not; the important point is that in all general chemical teaching substances are supposed to act *together*, and that when one substance acts upon another it must, itself, be changed into something entirely different.

It will be seen that this way of looking at things is but a crude and partial expression of the facts of chemistry, and by no means adequate, in the increasing demands of men, for explaining what men want to know, or for helping men to do what they want to do. There is a newer, deeper knowledge, a new province of chemistry, which is beginning to assume a suzerainty over the whole chemical realm, and, indeed, to lay down laws for other sciences. This new knowledge is Physical Chemistry, and one important branch of Physical Chemistry is *Catalysis.* From our knowledge of catalysis Lully's dream of a sublimated medicine seems by no means so wonderful as he doubtless intended it to appear.

There exist certain substances which may lie in a vessel seemingly inert, and yet by their mere presence may dictate what actions shall or shall not take place therein. A thing which has this commanding power is a *catalyst,* and the process is *catalysis.* A catalyst has the same chemical composition at the end of the reaction as it had at the beginning; it is chemically unchanged by what it does. A very small quantity of a catalyst will bring about the chemical transformation of enormously large quantities of substances which lie in its presence. It must be plain to the reader that such catalytic bodies must be very interesting in what they teach us concerning the inner properties of matter, and that they ought to be very valuable if harnessed to industry and the needs of every-day life. We shall illustrate some of these catalytic actions in a few simple test-tube experiments, which, while they are not dramatic or sensational in their appearance, serve to demonstrate clearly some of the fundamental characteristics of chemical action; and we shall proceed from these experiments to their technical application. It will all serve to show, incidentally, how far in advance of scientific teaching in the schools is scientific discovery, both in facts and in the interpretation of facts, and how remarkably quick the Germans are to apply present discovery to the practical ends of German industry.

The mere presence of a trace of a foreign body may make an insoluble body soluble. The following puzzling fact is known but to few: Chromic chloride is a curious substance that exists in two forms, soluble and insoluble. The "insoluble" violet crystals may be left under water for days unaffected, as in Fig. 1 *(a)*; but drop into the test-tube a trace of chromous chloride, even 0.000025 of a gram, and the violet crystals hasten to bury themselves in the water, the temperature rises, and the indigo-blue liquid results, as pictured in Fig. 1 *(b)*. The mere presence of a trace of the catalyst has suddenly let loose the powerful affinities lying latent in the violet crystals and the substance is dissolved. It is almost as curious as though a pound of salt thrown off the Battery should dissolve Manhattan Island. This is an example of what is called physical catalysis, for the chemical properties of the chromic chloride are the same after as before; it has simply passed into solution.

Turning now to chemical catalysis, we are confused by the number of examples, for, owing to the recent ferment of investigation, it would take a dictionary to chronicle them. The metals, for example, are wonderful in the number and importance of the chemical changes which their mere presence inspires. Consider the following example:

The test-tube, Fig. 2 *(a)*, contains hydrochloric acid and tin; there is no obvious sign of an action. But let fall a drop of a solution of platinum into the tube, and the result is immediately apparent; there is a vigorous action between the acid and tin. As shown in Fig. 2 *(b)*, the tube is filled with bubbles of evolving hydrogen, and yet the whole vigorous action was initiated by the mere presence of a trace of platinum.

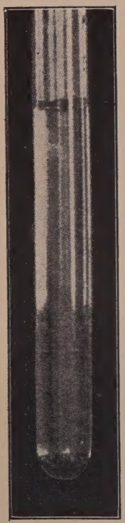
All kinds of metals and compounds of metals have this powerful "presence," and perhaps the most astonishing thing about them is the minuteness of the quantity which is necessary to bring about powerful reactions. Thus 0.0004 gram of this platinum will cause the union of some ten quarts of oxygen and hydrogen; 0.000001 gram of potassium permanganate will effect one reaction; while 0.000,000,000,000,1 of a thimbleful of blue vitriol solution will effect another, and so with other examples indefinitely. It must be remembered, too, that in all such cases of pure catalysis the trace of the catalyzing substance is quite unaffected by its remarkable exertions; it remains as potent as ever, and may be used over and over again.

ENZYMES

But inorganic substances are not the only catalysts. Many living organisms have the same power. The whole subject of fermentation is based upon chemical changes brought about by the power of microbes or bacteria. The "yeast plant" decomposes sugar into alcohol, the "vinegar plant" transforms alcohol into acetic acid, the "lactic ferment" changes sugar into lactic acid, and the "nitrous and nitric ferments" transform ammoniacal products into the nitrates of the soil. The fermentative power seems to reside, either altogether or in many cases, in certain substances which are secreted by the protoplasm of the microbe and not in the power of the microbe *per se.* This seems demonstrated in the case of the "yeast plant" mentioned above.

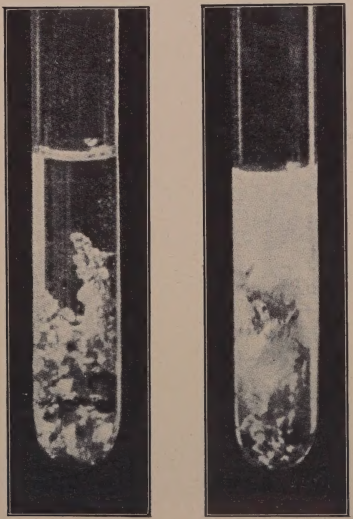
Fresh yeast has been ground up with sand, squeezed through cloth under a pressure of 7000 pounds to the square inch, and the resulting juice precipitated with alcohol. The precipitated substance still has its power of transforming sugar into alcohol. Catalytic substances which may be extracted from living cells without losing their activity are called *enzymes.* The alcohol-producing enzyme cited above is called zymase.

Enzymes are catalysts because, in quantities indefinitely small, they bring about chemical transformations indefinitely large. Their number is extraordinarily great. There is diastase, from barley-malt, which, like the ptylin of the saliva or amplopepsin of the pancreatic juice, has the power of transforming starch into sugar; pepsin, in the gastric juice, which



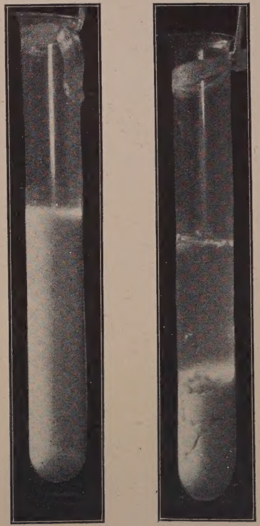
(a) (b)

FIG. 1.—PHYSICAL CATALYSIS



(a) (b)

FIG. 2.—CHEMICAL CATALYSIS



(a) (b)

FIG. 3.—THE CATALYTIC ACTION OF AN ENZYME

decomposes insoluble albuminous food-products into a soluble form; and invertase, another enzyme from "yeast," which has the power to transform 200,000 times its weight of sugar into *invert* sugar, quite a different substance. The example which we have chosen to illustrate the catalytic power of an enzyme is the action of rennet, an enzyme extracted from cheese.

Fig. 3 *(a)* contains soluble casein from skimmed milk. The introduction of a drop of dilute rennet works a transformation, as seen in Fig. 3 *(b)*.

One part of rennet will transform 400,000 times its weight of casein.

Throughout the whole range of animal and vegetable life the catalytic enzymes or ferments are busy. They are vitally and fundamentally concerned with life, and physiology is rapidly resolving itself into a branch of catalysis.

So many catalytic agents are "colloids," and the colloidal condition is so tangled up with catalytic action that we must diverge briefly to give the colloidal condition separate consideration.

By colloids we mean, here, "colloidal suspensions."

These are bodies that will, like true solutions, lie in a liquid until doomsday without falling to the bottom of the flask.

It is impossible to separate them from the liquid by filtration, because they pass through the pores of the filtered paper; unlike true solutions, however, they may be separated when the liquid is forced through an animal membrane. They consist of particles so finely divided that they are held mechanically suspended in the water. They are so difficult to deal with that in the past they were emphatically called "messes," and were for the most part left severely alone.

Enzymes belong in large measure to this class of bodies, and the physiologists who attempted to deal with them were for a long time treated by chemists with scarcely veiled contempt for their somewhat futile efforts.

Thanks, however, to the modern *rapprochement* between physiologists and chemists, means for investigating them have been devised—and this is very lucky indeed, because of the discovery of colloidal metals. These substances were prepared first by Professor Bredig, and their significance in the phenomena of catalytic action makes his discovery one of the first rank. Their preparation may be accomplished, now, by anybody.

To prepare colloidal platinum, two wires of the metal are dipped into pure water, and an electric current of ten amperes and forty volts is passed through the wires. The latter are then separated the barest fraction of an inch, so as to form a tiny electric arc about half an inch below the surface of the water. At first the arc is obtained with great difficulty, but soon, for reasons more or less unknown, the ends of the wire grow bright, and the arc may be maintained for several seconds at a time.

With every flash, dark clouds roll away from the arc and disappear in the liquid, which gradually passes through varying shades down into a deep brownish black, and the colloidal preparation is complete (Fig. 4). Colloidal gold yields a beautiful ruby liquid, and silver a yellow one. There is no question about the character of these liquids. They obviously consist of water, containing finely divided particles of the metals concerned, which have been torn off by the arc and pelted into it. The whole question hinges upon their state of aggregation. Are they molecules of metal dissolved in the water like sugar and salt, or are they particles of metal many times larger than molecules, too small to be seen, but yet mechanically suspended in water like dust in air? Are they, like so many of the enzymes, true colloidal suspensions? From what we are about to describe it is important to settle this question beyond peradventure, and this has been done by a beautiful instrument little known and vastly important, the ultra-microscope (*vide* Chapter VI). With its transcendent powers it was utilized by Professor Bredig to determine the nature of colloidal metals.

The sight of a colloidal solution of gold, as it lies in the ultra-microscope, is one never to be forgotten. The beautiful ruby color of the liquid is gone, and in its place is a starry night. The whole field of vision is scattered with glittering points of light, now green, now red, now yellow, and one finds one's self wondering whereabouts in these mazy configurations is the Great Bear or the North Star. Soon it is seen that these stars of the infinitely small are rotating rapidly on their axes (the so-called Brownian movements), and from that time on the fascination of the sight draws one's eyes again and again to the eye-piece. The particles of gold which one sees under these conditions consist, according to Professor Bredig, of about 200 molecules. We see these particles pretty much as we see the stars. These colloidal solutions, therefore, are true colloidal suspensions. They consist of water holding in suspension infinitesimally small rotating particles of a metal, and we have gone into the business of proving this for the reason that they are immensely important in our study of catalytic action. They are strong catalysts, and they are to a remarkable extent analagous in their properties to the enzymes. In no respect is this more evident than in the catalytic action of colloidal metals and enzymes on the decomposition of hydrogen peroxide.

Hydrogen peroxide is that substance so famous as a bleaching agent and as an antiseptic. It is unstable, and slowly breaks down into water and oxygen. This decomposition is brought about with a rush by a drop of colloidal platinum. So sensitive is the peroxide that one gram of colloidal platinum in 300 millions of water

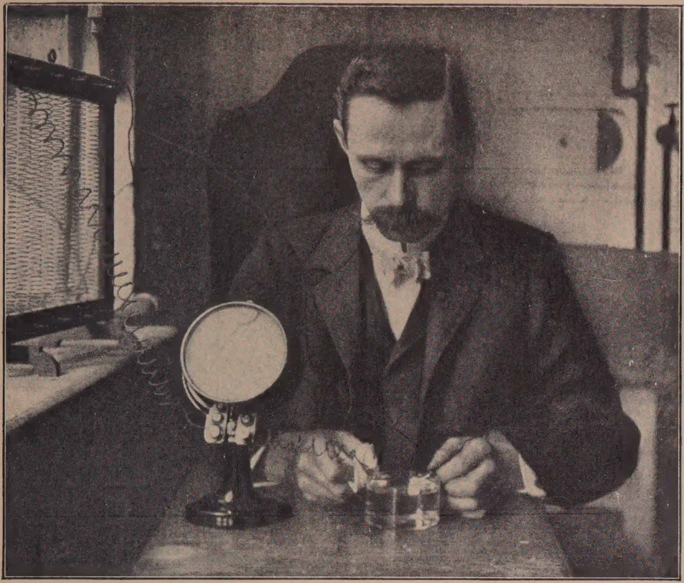
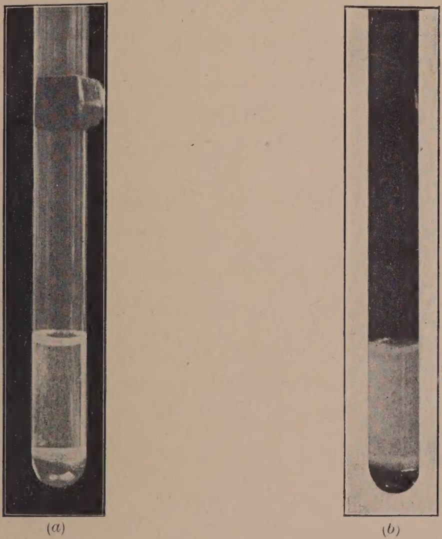


FIG. 4.—PREPARATION OF A COLLOIDAL METAL



(*a*) (*b*)

FIG. 5.—PERIODIC CHEMICAL ACTION

is efficacious in accelerating the decomposition. But the peroxide is equally sensitive to the enzymes. Thus, a drop of blood brings about the same effervescence. This is due to the presence of a newly discovered enzyme in the blood called hæmase.

We have much reason to believe that this similarity of action is due to some identity of cause—that it is no mere accident—no mere analogy.

We find that both classes of bodies are colloids, that small quantities of alkalies accelerate their influence, while larger quantities retard it, and that acids retard them both.

Furthermore, the activity of both is influenced by raising the temperature and in the same way. Finally, and very importantly, certain substances have an extraordinary power of retarding or inhibiting altogether the catalytic action of both. These substances we shall call catalytic paralyzers. Such a substance is prussic acid. In both cases the action is paralyzed, and the liquid lies dead in the tube. Twenty-seven parts of prussic acid in forty millions of water is active in retarding the catalytic action—a case of homœopathic infinite dilution with a vengeance. In a similar way, and in similarly small quantities, act cyanogen iodide, iodine, corrosive sublimate, sulphuretted hydrogen, carbon monoxide, phosphorus, arsenic, carbon disulphide, and very many other substances. Not only so, but both colloidal platinum and the enzymes (specifically blood) *have the power to recover* from the effect of some of these paralyzers. The effervescing decomposition of the peroxide first "slows up," and then gradually regains its vigor as time goes on.

The reader may now ask: "Why all this coil about colloidal metals and enzymes? Suppose they do have some identity of cause in the production of their effects? What then?"

There are several reasons why the matter is important. First, these enzyme-catalysts are substances that lie in wait at every kink and corner in the body; they produce by their mere presence enormously important results, and from their actions they seem to lie ensconced about the very secret of secrets—the very nature of life, more, even, than protoplasm—and this secret men most devotedly wish to discover. Again, it will be noticed that these "paralyzers" of catalytic action are *deadly poisons*. Enzyme paralyzing seems to mean animal poisoning. Now, who knows but that if we could discover the mechanism of poisoning we might be on our way not only to the secret of life, but to its maintenance? But the enzymes are bodies exceedingly complex, and difficult to isolate and to deal with; colloidal platinum, on the contrary, consists simply of rotating particles of a metal suspended in water. Hence, if there is an identity of cause in the effect of both, it is with colloidal metals that humanity has its chance. One must take care not to be led too far by the seductive character of this analogy. The identity of cause that we think we see may be a subordinate or comparatively insignificant identity. Besides, the identity is not absolute. Poisons to enzymes are not always poisons to platinum, and this has led some people to conclude that the similarity of action in all the respects noted above is a mere coincidence. This is purely absurd.

For an identity of cause, it is not necessary that both should behave in a perfectly identical manner with all substances that they affect, for these substances, alike in the one thing, may be very different in others.

The mere presence of minute quantities of certain substances will greatly retard or bring to a full stop many chemical reactions. They are different from the "paralyzers" considered above, for the "paralyzers" stop the catalysts; these substances act in the reverse way to a catalyst, and the phenomenon is known as negative catalysis. Among the difficulties of explaining catalysis, negative catalysis is perhaps the hardest nut to crack.

A catalytic phenomenon much thought about and worked over in this day is periodic chemical change. Try the following experiment:

Pour a little clean mercury into a very clean test-tube, and add a little ten per cent. peroxide of hydrogen. Be a little patient, and you will see your first instance of "vibratory" chemical change.

The mercury is a catalyst, and its mere presence decomposes the peroxide into water and oxygen gas; but more than this, the evolution of the gas is periodic. About every half second a bronze-colored film appears on the surface of the mercury, and it is followed immediately by a burst of gas. This occurs over and over again with beautiful regularity. Figs. 5 *(a)* and 5 *(b)* photograph the reaction caught in its two phases. This phenomenon is inexplicable, and it is significant.

Men are more and more eager to discover a mechanical explanation of vital action, and they are trying now to show that the pulsations of the heart, the periodic movements of plants, the pulsations of the vacuole of an amœbra, may all find an adequate explanation in periodic chemical action.

The reader may possibly be curious to ask for the "why" of these curious facts of catalysis. There is no answer. The very abundance of the theories proves their insufficiency. Two have special prominence—the theory of sympathetic vibration, and the theory of intermediate reactions. In accordance with the first, a catalyst acts by its mere presence, because it has a certain period of vibration which, when it is placed in an inert mixture, causes the particles of the mixture to vibrate at such a rate that they fly to pieces, and thus interact. The theory is perfectly invulnerable—and perfectly useless, for it lies outside the possibility of experimental verification. The intermediate compound acts thus: Two substances, A and B, when placed together would react if they could. A third substance, the catalyst C, is introduced. A reacts with C (the catalyzer) to form the compound A C; thus, $A+C=A\,C$. But A C is unstable, and immediately reacts with B $A\,C+B=A\,B+C$. A and B are thus brought together to form A B, and C (the catalyst) is let loose to do the same work over and over again.

This doctrine is fanatically preached by many men prominent in catalytic work. It is comfortable, and much may be said of it so long as you do not ask them to show you the intermediate compound A C. In no single instance have they been able to do this beyond question. In addition, you must not ask them to explain negative catalysis. The fact is, we do not know the cause of the mysterious influence which a catalyst exerts.

We have lifted merely a sod or two of this great field of catalysis in order to show the reader what treasures lie beneath, but sufficiently, we hope, to convince him on *a priori* grounds of the propriety of Ostwald's statement when he says: "If one considers that the acceleration of reactions by catalytic means occurs without the expenditure of energy, and in this sense *gratis,* and that in all technical work, including chemical, time is money, it is evident that the systematic use of catalytic aids may lead us to expect the most far-reaching changes in technology."

Just how rapidly these "far-reaching changes" are proceeding it is the purpose of our article to demonstrate. Consequently we leave untouched the old chance applications of catalysis. Men used its aid without knowing even the word, just as they used fire without knowing the meaning of combustion. Catalysis is as old as drunkenness, for alcohol is produced by fermentation, and ferments are catalysts.

Intelligent catalysis began with the Deacon process. Here, in any factory using it, we find immense quantities of hot hydrochloric acid and air passing over some thirty-six tons of broken brick impregnated with copper chloride, only to issue thence transformed into chlorine and water. This chlorine afterwards passes into the form of bleaching-powder, chloroform, and a dozen other chlorinated substances. The mere presence of the chloride of copper has worked the miracle of transforming, *gratis,* a cheap product into a dear one; and of transferring money from the pocket of one man to the pocket of another to an extent which is very carefully kept secret, but which is immensely greater than most technologists appreciate. The hydrochloric acid used for this purpose is a by-product from the old Le Blanc process for the manufacture of soda, which would long ago have passed into the limbo of forgotten arts without its aid.

Another necessary prop to the process is the Claus-Chance process. In every great soda factory of this type there are enormous piles of "tank waste"—useless, and a menace to the neighborhood. From this "waste" sulphuretted hydrogen is obtained, which, mixed with air, passes into a "Claus Kiln," where it makes the acquaintance of oxide of iron. Under the persuasive influence of this substance, it is transformed into sulphur and water. The sulphur is, of course, entirely valuable: the oxide of iron remains quite unaffected by its valuable exertions, except that it becomes gradually transformed into artificial iron pyrites, which is more efficient than the original oxide. Strange to say, if one attempts to use "natural" pyrites instead, no catalytic action whatever is obtained and no sulphur is produced; why, nobody knows; it is a mystery shrouded in the word "catalysis." Many counties in England are dotted over with these factories.

Still another interesting manufacture in this connection is the Hargreaves-Robinson process for the production of "salt-cake" (sodium sulphate) and chlorine by passing a mixture of hot sulphur dioxide and air, obtained by roasting pyrites, over common salt impregnated with a chloride of copper. Four and a half pounds of copper to a ton of salt works the wonder, and since pyrites and salt are cheap and "salt-cake" and chlorine are dear, it is naturally very profitable. Though millions are locked up in these processes, they pale into insignificance beside the contact process for the manufacture of sulphuric acid—perhaps the greatest triumph of modern technical knowledge. Sulphuric acid, oil of vitriol, is the king of chemical products. Its uses are literally innumerable, and the amount of sulphuric acid availed of by a country is a very fair measure of its civilization. The total consumption of sulphuric acid for the year 1904 exceeded eight billion pounds.

Everybody makes sulphuric acid from sulphur dioxide, air, and water. The sulphur dioxide, for the most part, is obtained by roasting iron pyrites. Now, air is cheap, water is cheap, and iron pyrites is almost as cheap as the cost of hauling. Every part of the process is easy with one exception—the necessary intermarriage of the oxygen of the air with the sulphur dioxide from the roasting. This has been consummated in the past by great lead-lined chambers, aggregating sometimes 200,000 cubic feet of space, and under the catalytic influence of the oxides of nitrogen. A plant manufacturing sulphuric acid covers many acres of ground and employs millions of money. The factories are, naturally, under the control of trust organizations, which, although so powerful, are in the embarrassing position of being what is called a "threatened industry." The enemy has its seat on the banks of the Rhine.

The "Badische Anilin und Soda Fabrik of Ludwigshafen am Rhine" is a name to conjure with in

Germany, and no robber castle on that historic river was ever more dreaded than is this modern fortress of industry by those against whom it is commercially and inimically inclined. The " Badische " makes use of a simple-seeming fact discovered by Peregrine Phillips in 1831, that the sulphur dioxide and air will unite with the most agreeable ease in the mere presence of platinum—a case of pure catalysis. Nothing came of this discovery seventy-five years ago, because the fact only *seemed* simple, and because in England there is no sympathy between learning and manufacture. In Germany, however, there is no tariff wall against English ideas, and eventually this fundamental fact (after it had been added to by the labors of many men) fell into the capable managing hands of the " Badische." Of the progress and issue of this great struggle only a scientific Homer could adequately sing—how difficulty after difficulty rose up to smite them, and how in consequence plant after plant went to the scrap-heap. They found they were using little air when they ought to use much; they found they were using heat when they ought to use cold; and, most deadly and costly difficulty of all, they found their platinum was being constantly poisoned and ruined from the presence of minute impurities in the roasted gas. Their worst enemy was arsenic; and it is easy to poison a catalyst.

After the most heroic efforts and the enormous expenditure of knowledge and time and labor and money, they won. The roasted sulphur gas and air are scrubbed and dried and cooled and passed over platinized asbestos, only to be collected therefrom as 116,000 tons of sulphuric acid for the year 1900, and over 200,000 tons for 1904. But there are so many ways of killing a cat that it is not surprising that other catalytic processes have been derived for this same purpose. The transriparian rival of the "Badische," the Verein Chemische Fabrik at Mannheim, employs oxide of iron as the catalytic agent. Another company, Meister, Lucius, and Brüning, of Höchst, employs a protected variation of the Badische process, while the Actien-Gesellschaft für Zinc Industrie is perhaps the most serious rival of all. This company employs a soluble salt impregnated with platinum and puffed up into a porous condition. In 1903 it had no less than twenty-three plants working; and the success of this company gains additional significance to the American manufacturer from the fact that its interest was primarily concerned in the utilization of a by-product—the waste sulphur from the zinc-blende. Other catalysts, such as vanadium, chromium, tantalum, etc., are now proposed, and the manufacture is in a ferment.

The enormous dividends paid by these companies attest the profitable nature of the application of pure science to industry.

By all these processes concentrated sulphuric acid can be made cheaper than by the old "lead-chamber" process. With the dilute acid the advantage is not so clear. The great lead-chamber process, therefore, is in a parlous state. It is a " threatened industry." Now threatened industries, like threatened men, sometimes live long; and there is no doubt that, taking alarm in time, these great companies are making strenuous efforts to improve their process so as to gain the necessary margin of safety. So far as to-day is concerned, the new process has even reacted favorably upon the old. As for to-morrow, it is hard to say. The new process is improving itself so rapidly that the old is not unlikely eventually to seek refuge in the scrap-heap.

The " Badische," however, uses one hand to wash the other, and both to wash the face. In developing this huge sulphuric-acid synthesis it had in mind only incidentally the displacement of the old lead-chamber process. Fundamentally, its object was the direct consumption of the acid by itself in quite another process which, equally, has been one of the most brilliant achievements of technical chemistry.

The commercial synthesis of indigo is a process which has reversed the economic relations of states. Only yesterday, so to speak, twenty-five million dollars' worth of indigo was exported every year from India and the surrounding islands and countries. This was obtained from the indigo-plant by a crude and ignorant fermentation-catalysis that originated long before authentic history. The indigo-planters were a powerful, self-sufficient race of men who passed the time fleetingly, "as they did in the golden world," in the employment of serf labor and an easy production. Consumers of indigo were continually in trouble over the variable purity and quantity of the product. It was natural, then, that scientific manufacturers, such as the "Badische," should wish to supplant this ignorant production by the same substance made pure and out of coal-tar. In order to accomplish this three steps were necessary—(1) the determination of the constitution of indigo, (2) the synthesis of indigo, (3) the commercial production of synthetic indigo. The first and second problems took fifteen years of Baeyer's life, and the third problem, its commercial production, took nearly twenty years longer.

The first promising synthesis of indigo was perfected by the "Badische" up to the competing point, and was then calmly discarded because it started with toluene as a raw material, and there was too little toluene in the world to extinguish the annual 11,000,000 pounds of natural indigo. Nothing less than the complete extinguishment of natural indigo would satisfy these men. It was then that its catalytic synthesis from naphthalene was discovered. Naphthalene is obtained from coal-tar, and is both abundant and cheap. We need not inflict upon the reader the names of fear possessed by the substances through which naphthalene passes on its way to indigo. Our subject is catalysis, and the validity of the whole process depends on a catalytic operation — the mere presence of mercury (or mercury and copper) — in bringing about the easy action of sulphuric acid in oxidizing naphthalene to phthalic acid, the first step in the process. This interesting essential (the advantageous presence of mercury) was discovered through some mercury found at the bottom of an experimental flask—the result of a broken thermometer!

Through this little accident in 1897 synthetic indigo became a commercial reality, after the "Badische" had spent over $4,500,000 on the plant and preliminary experiments. In 1903 the German export of artificial indigo amounted to $6,250,000. In 1904 the export of natural indigo from India amounted to less than thirty per cent. of what it had been, and, as a matter of fact, artificial indigo is now actually being imported *into* India. The reason is, briefly, that the artificial indigo from coal-tar is not only indigo: it is *pure* indigo, and cheaper than the natural product.

As practised by the "Badische," 10,000 tons of naphthalene, over 1,200,000 pounds of ammonia, 4,500,000 pounds of glacial acetic acid, and 10,000,000 pounds of salt are annually consumed. The 50,000 tons of sulphuric acid which is required are obtained from the contact process to which we have referred.

The indigo produced by this interesting catalysis of mercury would require the cultivation of an area of more than a quarter of a million acres of land in the home of the indigo-plant. But the "Badische" has no monopoly. There are no less than three other processes distinctly different for the production of the same product and in large operation on an industrial scale. It is plain that the indigo-planter's occupation is gone.

The interesting catalytic process called the "Catatype Process" was devised by Professor Ostwald and Dr. Gros. It is concerned with the making of photographic prints without sunlight. Since, thanks to Dr. Gros, the writer was made practically acquainted with this process at the works of the Neue Photographische Gesellschaft, at Steglitz, the reader may try it for himself. We already know how easily peroxide of hydrogen decomposes in the mere presence of metals. This is, here, the primary fact. A piece of cotton is dipped into a mixture of peroxide and ether, and is then quickly rubbed over the face of a negative. It is then left for a brief instant. During this instant the ether evaporates, and wherever there is silver on the negative the peroxide is catalyzed by its presence into water, and wherever there is no silver the peroxide is left unaltered. There is thus on the face of the negative an invisible positive of peroxide. Place, now, the negative

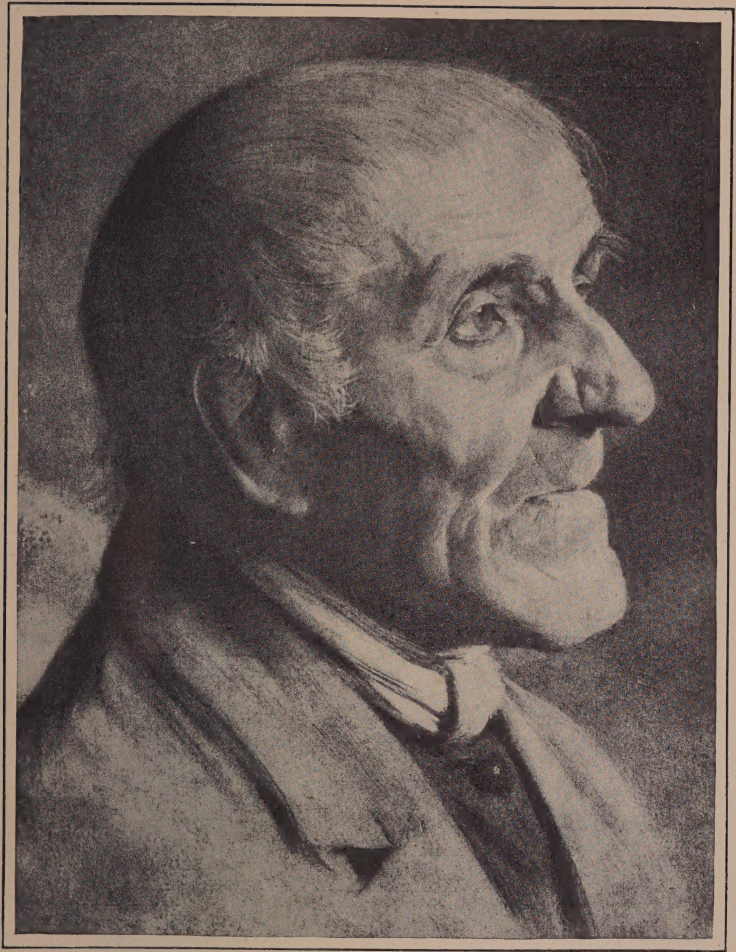


FIG. 6.—CARBON PRINT MADE BY THE CATATYPE PROCESS

in contact with a piece of gelatinized paper in a "printing frame," and this invisible positive is at once transferred to the paper, and on placing this paper immediately into an alkaline solution of manganous sulphate, for example, you will obtain a beautiful picture in brown tones. With an alkaline silver solution the print will be black. The process is peculiarly applicable for the easy production of beautiful "carbon" prints. The pigmented and unsensitized paper is brought into contact, as described above, and is then treated in the ordinary way. The carbon print reproduced in our illustration (Fig. 6) did not take two minutes to make. By the time this book is printed, the process will be on the German market.

The metals are catalytically and industrially active in a number of other ways. By a process devised by Ostwald, the ammonia obtained in the manufacture of illuminating gas is mixed with air and passed over platinum with the production of nitric acid, and a large experimental plant using this process is now established on the banks of the Rhine. Platinum-black is also responsible for the large quantities of "formalin" made by passing over it the vapors of wood-alcohol mixed with air. It is also the active substance in the well-known formaldehyde lamp and in the self-lighting gas-machine. Alcohol vapors mixed with air are now converted into acetic acid by the same agency; crude acetic acid is now purified by it, and the important substance vanillin is prepared by its presence. The mere presence of copper compounds brings about the manufacture of various dyes, such as anilin black, methyl violet, fuchsia, and others.

Lead and manganese compounds by their presence act as "dryers" in the oxidation of linseed-oil. A zinc tube through which the vapors of alcohol and air are passed establishes a process yielding eighty per cent. of aldehyde. The compounds of iron are concerned in metallurgical operations, such as the roasting of sulphides, and in other ways. So is the oxide of calcium (lime) in lead metallurgy. The mere presence of nickel in transforming oleic acid into stearic acid is establishing an important process for using up what has been, in large measure, a waste material. Barium carbonate and pumice-stone effect the easy commercial manufacture of acetone from acetic acid.

But there are industrial catalysts other than metals. For example, large quantities of the valuable solvent carbon tatrachloride are now manufactured in the presence of iodine; and carbon purifies alcohol and water. A fat-splitting enzyme extracted from castor-oil seeds brings about the decomposition of fats in an easier way than by lye, and permits the use of carbonates instead of lye in the manufacture of soap. In the battle between electrolytic alkali manufacture and the ammonia-soda process this fact is likely to play a decisive part.

CATALYSIS

The writer wishes to express his obligation to Professor Bredig, of Heidelberg, who kindly placed at his disposal the collected literature of this widely scattered knowledge of which so slight a résumé appears in this place, and to his students, many of them Americans, for making him practically acquainted with the important problems upon which they are now engaged.

III

THE PROBLEM OF THE FIXATION OF NITROGEN: WHAT MAN MAY DO WHEN HE MUST

THE romantic deportment of the nitrogen atom is fascinatingly interesting to the student of chemistry. Wherever he looks he sees that the living, moving, doing thing in the world is nitrogen; it is at once the most restless and the most powerful of the elements. When nitrogen enters into a collocation of atoms we invariably expect the collocation to do something active, whether good or ill; for the nitrogen compounds have properties and qualities, they are never inert.

So it is that, entering into combination with a few other atoms, it will yield us the most delicate and delicious of perfumes, while it is equally ready to join forces with others to produce substances whose smell of utter vileness has the psychological effect of causing the experimenter to "wish he were dead." In the aniline dyes it enhances our clothing with a thousand beautiful colors, and in still another thousand forms it enters the chambers of the sick in the healing guise of all the synthetic medicines. It lurks in prussic acid, the ptomaines, and a host of deadliest poisons;

it drives our bullets in the form of gunpowder; it explodes our mines as dynamite and guncotton; it dissolves our metals as nitric acid; it extracts our gold as cyanide; and in an infinity of ways it menaces or ministers to mankind. Nitrogen-containing substances, then, are active substances, and their activity seems to be due to a certain "temperamental nervousness" of the nitrogen atom which sends it flying on the slightest pretext from one atomic community to another. On this account we call nitrogen a "labile" element.

But it is only when we consider nitrogen in its relation to life that we see how truly momentous is this fact of its lability. We have been accustomed in the past to ascribe to carbon the rôle of life-element paramount, but the more the question is studied, the more does it appear evident that the carbon constituent of the body is the mere brick and mortar of it, good enough to constitute its physical substratum, and good enough, too, to burn as fats and carbohydrates to maintain its fires, but that the working, building, "vital" thing, the thing that is the moving-spring of protoplasm and that brings about the continuous adjustment of internal to external conditions that we call life, is the versatile, restless nitrogen.

It looks as though the living being constituted a vast unstable plasma in which the nitrogen atom, with oxygen on the one hand and carbon or hydrogen on the other, very much as it is in nitroglycerin, swings the atoms of the living body through all the multiplex atomic relations of growth and decay. The lability of living substance is the lability of the nitrogen atom, and we may say, with much more propriety than "Ohne Phosphor kein Gedanke," "Ohne Stickstoff kein Leben"—no life without nitrogen.

And yet—and this is a most interesting thing—this nitrogen, which when combined with elements of another kind is so energetic and so useful, is, in its carefree, solitary condition, a stubborn, lazy, inert gas. In this, the elemental condition, it is one of the most abundant and pervading bodies on the face of the earth. It constitutes four-fifths of the air that blows in our faces, and so much of it there is that every square yard of earth's surface has pressing down upon it nearly seven tons of atmospheric nitrogen.

Chemically speaking, it is all but unalterable, though the "all but" is vastly important to us. One or two metals, such as calcium and magnesium and a few compounds of metals, may be made to unite with it. We find, too, that certain organisms, bacteria—"nitrifying microbes" they are called — have within their little bodies laboratories for attaching nitrogen to other elements, though the mechanism of this action no man understands. Still again, we find that the lightning flash will cause the nitrogen and oxygen of the air to combine in the path of its streak to form nitrous acid, or that it will cause the nitrogen and water vapor to react to form ammonia. Outside, however, of the minute quantities which are extracted from the air in these various ways, the whole great ocean of atmospheric nitrogen under which we live and move maintains in a chemical sense a listless, useless lethargy.

Now, nitrogen which is united with other elements (it matters little which), and which is so temperamentally nervous and active and useful we call "fixed" nitrogen, while the nitrogen which exists in the elemental lethargic condition of the nitrogen of the air we call "free" nitrogen, and the object of this chapter is to present the various modern attempts to solve the problem of transforming in large quantities the free and useless nitrogen into the fixed and useful kind. This problem is of immense importance to the whole world—to every race, to every human being; for as a matter of hard, cruel fact we either must solve this problem or starve. This statement is a most unlikable one, for it is sensational and alarmist, but how true it is easy to show.

The invaluable "fixed" nitrogen which we have within us, and which we are continuously using up, we must continually restore. In order to do this we eat nitrogen. We eat it in the form of animal food or of certain plant products, such as wheaten bread. But plants and animals, too, depend upon the soil for every trace of the nitrogen they contain, and the soil in its turn has won it from the reluctant air through the slow accumulations of the washing rain, from the lightnings of a million storms, or through slow transformations by billions of nitrifying organisms through what, so far as we are concerned, is infinite time. Not only so, but the valuable nitrogen-containing substances we employ in our civilization are in the same parlous position of depending upon the soil. Every cannon-shot disperses in an instant the fixed nitrogen which it required millions of microbes centuries to accumulate. We filch this nitrogen from the soil immensely faster than it is restored by natural processes, and the land grows sick and barren and refuses to grow our crops.

Everybody knows what we must do to cure the land: we must use manure or fertilizer. In other words, we must mix with the soil substances containing fixed nitrogen which the plant may utilize in building up what we must and will have—bread and meat; to say nothing of other substances, such as gunpowder and dyes and medicines. In the olden time natural manure was sufficient to meet the demands of sparse populations accustomed to poor food and little of it; but in these days of rapidly multiplying civilized man, who requires more food and better food, particularly wheaten bread, the natural manure of the world is a mere drop in the bucket of his wants; and this would be true even if he could utilize the fixed nitrogen of the sewage and drainage of his towns, which, it is horrifying to learn, England alone hurries down her watercourses to the sea to the value of $80,000,000 a year.

As a matter of fact, we were long ago forced to the employment of three other fertilizers. The first of these was Peruvian guano. This substance was produced from the excrements and remains of sea-birds deposited in a very arid region. It contained fixed nitrogen in the form of about twenty per cent. of ammonia. We say the first "was" guano, for while in 1856 the year's sale amounted to 50,000 tons, to-day it is practically nothing at all. We have eaten it up.

The second fertilizer is ammonium sulphate. This is obtained as a by-product in the distillation of coal-tar in the manufacture of coke. In 1900 the world's production of ammonium sulphate was 500,000 tons, worth some $20,000,000. But this amount is a fixed quantity; we may have so much and no more from our coal-tar distilleries, and large as the amount seems it is inadequate to supply the one-hundredth of the imperious and increasing demands of our Mother Earth.

There is actually but one substance, the third, possible of being used on a world-wide scale as a nitrogenous manure. This is nitrate of soda, or, as it is called, Chili saltpetre. It occurs native over a narrow band of land between the Andes and the coast hills, a rainless district, where for countless ages the continuous fixation of atmospheric nitrogen by the soil, its conversion into nitrate by nitrifying organisms, its combination with soda, and the crystallization of the nitrate have been steadily proceeding against the time when, as now, earth's increasing family would insistenly demand it for bread.

In order to drive home to the reader the validity of the statement we are about to make, let us examine the pay-roll of the years. The Chili saltpetre-beds yielded, in 1860, 68,500 tons; in 1870, 182,000 tons; in 1880, 225,000 tons; in 1890, 1,025,000 tons; in 1900, 1,453,000 tons; and since 1900 every year has added 50,000 tons to the demand of the year before. The amount yielded in 1900 — 1,453,000 tons — was sold for about $27,000,000, one-quarter of it passing into the thousands of nitrogen compounds used in our civilization, and the other three-quarters into food through its fertilizing action in agriculture.

European and American agriculture and a hundred varied kinds of industry are thus wholly and implicitly dependent upon a tiny little strip of land in a South American republic, and upon the grace of the "Nitre Kings" who own it; and were the little republic to close her gates of export, hungry months and insurrections would follow as infallibly as the night the day. This is, of course, embarrassing and highly significant of the interdepending conditions of our civilization; but when we begin to estimate the amount of nitre taken out and the amount still remaining in the beds, and compare this amount with the crescendo ratio of the world's demand, we are more than philosophically interested—we are practically frightened. We see that what has happened to guano will inevitably happen to saltpetre. It is a matter of plain, hard, cold-drawn fact, as everybody now knows who knows anything about the Chili saltpetre-beds and the needs of agriculture, that these saltpetre-beds will not last longer than twenty years, if present conditions continue. About the year 1925, then, there will be no more nitre; and a year or two after that, or before it, famine will stalk on the lands of civilized men. This is acknowledgedly true if present conditions continue.

But the phrase, "if present conditions continue," contains the crux of the whole matter. Why should they continue? We have in the enveloping air an immense and inexhaustible supply of nitrogen—33,880 tons of it upon every acre of land. This is "free" nitrogen, and the world demands it "fixed." If man must fix the wandering air into his own bodily substance and into substances that are the implements of his advancement, he will so fix it, and within the quarter of a century which is his margin. Let us see how far we have progressed. In attacking this problem, man of necessity and convenience imitated nature. If the cosmic processes were too slow, it was for man to hasten them.

If there exist certain little organisms capable of fix-ing atmospheric nitrogen, why not favor them, breed them, multiply them to our needs? It was discovered by Hellriegel that certain leguminous plants, such as clover, beans, and pease, have near the base of their stalks little nodosities, little pimples, which turned out to be veritable colonies or cities of nitrifying microbes. These interesting microbes on every pea-plant, for mere board wages, work full time in turning over the useless atmospheric nitrogen to the plant in a fixed and useful form. Furthermore, it was discovered that soil inoculated with such microbes would grow these plants even when innocent of any trace of manurial nitrogen. The deduction is obvious. Why should we not blossom the desert with clover or pease, and thereafter plough the plants into the ground to afford manure for a succeeding crop of wheat.

In 1896 Nobbe and Hiltner produced this microbe in a commercial portable form under the name of "Nitragin." The experiment failed, as nearly all first experiments fail. The bacteria died, and, as it subsequently appeared, probably for want of suitable food, and possibly, too, from injuries suffered by secretions from the seed itself in the early stages of germination.

But to know the cause of failure was to succeed. They now supply this necessary nourishment in the form of grape-sugar and peptones added to the water in which they are distributed for spreading upon the soil. Their measure of success has been so great that we find to-day several manufacturers perfecting the method and establishing their processes for the wholesale production of nitrifying microbes.

Another method has been ascribed to Professor G. Moore, of the United States Department of Agriculture. He has sent out to the farmers of the country the dried germs packed in cotton. With them go two packages containing the food upon which they are to multiply when placed in water — one containing granulated sugar, potassium phosphate, and magnesium sulphate, and the other ammonium phosphate. The microbes, when placed in the solution of these substances, multiply with prodigious rapidity and serve to inoculate either the seed or the soil.

But there are many other nitrifying microbes besides those concerned with leguminous plants — dozens of tribes and hundreds of species, and investigation is to-day feverishly busy with them. We have every reason to believe that by multiplying nitrifying organisms alone, we should be able, in some measure, at least, to restore to the soil the fertilizing nitrogen which in the past we have wilfully and extravagantly wasted.

We have said that the lightning bolt burns the air in its path into oxides of nitrogen which, when washed by the rain into the soil, quickly become fixed into nitrates. We have learned to harness the lightning, and why should we not, therefore, imitate nature in this respect as well: utilize the combining efficiency of the electric spark, and burn the air to make our daily bread?

Over one hundred years ago the masterly Cavendish showed that with the tiny electric spark at his command this could actually be accomplished, and afterwards, by this very method, Lord Rayleigh burned the air to obtain the interesting argon hidden within it. In the powerful heat of the electric arc the air is a combustible gas, and Fig. 7 is a photographic illustration of a flame of burning nitrogen as it burns between the poles of a powerful induction-coil. The only reason that this flame, when once ignited, has not spread through the surrounding atmosphere and deluged the world in a sea of nitric acid is the peculiar fact that its ignition-point is above the temperature of its flame. It is not hot enough to set fire to the adjacent mixture.

Now, resting on every seven acres of earth there are 237,000 tons of nitrogen, sufficient, if we could burn it, to replace the 1,500,000 tons of saltpetre consumed last year. That we could burn this amount we know, but how to burn it in the cheapest way has still to be discovered. The whole question of its economic burning bristles with difficulties. Not only is the ignition-point above the temperature of its flame, but the temperature of the union of the nitrogen and oxygen of the air is perilously close to the temperature of

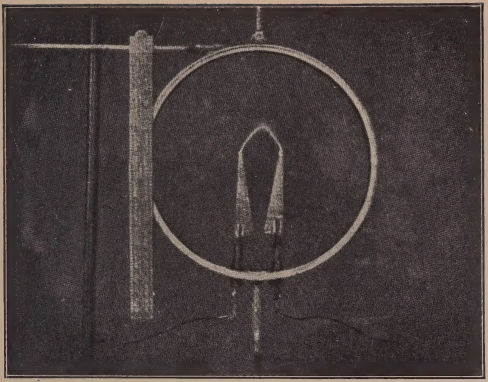


FIG. 7.—A FLAME OF BURNING NITROGEN

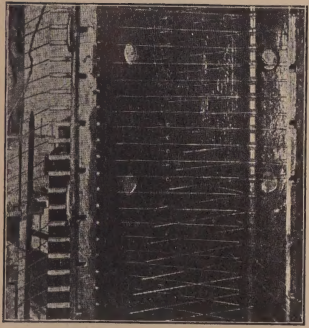


FIG. 8.—INTERIOR VIEW OF SPARKING-CHAMBER—NOT RUNNING

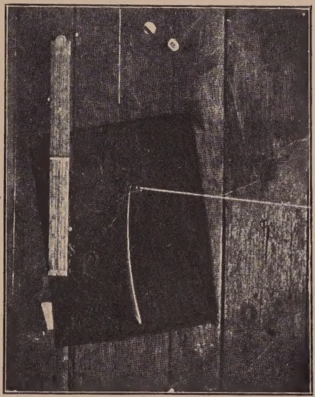


FIG. 9.—LENGTH OF SINGLE ARC

its dissociation, and there results an awkward equilibrium-point at which the nitrogen oxides are decomposed as fast as they are formed under the action of the arc. The prize of burning the air is certain riches, but how to proceed is the present question. Is it wise to employ arcs depending upon great electric intensity and small volume, or great volumes and small intensity? What kind of electrodes should be used—carbon or platinum, or what? Should the air be compressed, should oxygen be added to it, or should it be dealt with as it is; and, moreover, how shall we be rid of the equilibrium-point?

Among the race of chemists and chemical engineers, many men have been busy in the attempt to solve this momentous problem. There is the Atmospheric Products Company at Niagara Falls, where, through their earnest and intelligent efforts to solve this problem, Messrs. Bradley and Lovejoy have won high praise and cordial recognition from all the other workers in this field of investigation. The fact of this recognition is significant; it means that there is room enough for all. These gentlemen believe in sparks of high intensity, and they seem to have perfected their method to the limit of its powers.

The operation is carried out in a sparking-chamber which consists of a large cylindrical metal box lined in the interior with vertical rows of contact-points, each one of which is in connection with the positive pole of a dynamo generating a direct current of 8000 volts.

Fig. 8, which photographs a cross-section of the interior of this box, shows at the left of the picture the little positive contacts, each one connected with a wire leading to the dynamo. Now, inside the chamber rotates a central shaft provided with a similar set of *negative* contacts in the form of long rods, and all connected, of course, with the negative pole of the dynamo. But this cylinder is rotating at the rate of 500 revolutions a minute, and as each negative contact comes up to a positive, it strikes an arc which is drawn out and extinguished as the negative contact moves past and away from the positive (Fig. 9).

Since there are many revolutions and many contacts, there are no less than 400,000 arcs a minute. It is like the inner cylinder of a music-box ringing out sparks instead of sounds. But air is drawn through these multitudinous sparks, and each spark as it forms burns a small per cent. of the incoming air into oxide of nitrogen. The result is that some two per cent. of the outgoing air is converted into oxides, which are caught in absorbing towers of water with the formation of nitric acid, or of soda with the formation of saltpetre or sodium nitrite.

From data based upon the actual running of this plant, nitric acid may thus be produced from air and water at a cost of about two cents and a half a pound, and since the market price is some five cents and a half, it ought to be a profitable operation. But this is for nitric acid, and large as is the market for this substance, it is not limitless, as is the case with saltpetre. Whether the acid may be combined with soda to form artificial nitrate at a rate capable of competing with the natural product is still a matter of doubt; it depends on the price of soda.

Away off on the coast of Norway, where they have cheap water-power and cheap labor, still other men are engaged in the practical elucidation of this same problem. Professor Kr. Birkeland and Dr. S. Eyde, of Christiania, have developed a process by which the air is conveyed into a series of ovens. Each one of these ovens contains two metal electrodes, between which plays a high-pressure flaming electrical arc. The arc is moved rapidly hither and thither by a powerful magnet, in such a way that the maximum amount of oxidation is obtained.

These electrodes are of copper, approaching each other within one-third of an inch. In order to prevent fusion, they are hollow, and are cooled by the circulation of water. An alternating current of from 3000 to 4000 volts is used, and the diameter of the flame produced is six feet. By means of blowers 2649 cubic feet of air are gently forced through each furnace every minute, which amount of air, after leaving the furnace, is charged with about one per cent. of nitric oxide. After leaving the furnaces the hot gases pass first through a steam boiler, where they give up part of their heat to raise steam. Thence they enter the absorption-towers, which are about fifty feet high, built of granite slabs and filled with lumps of quartz over which the water trickles. From tower No. 1, fifty per cent. of nitric acid is drawn off; from No. 2, twenty-five per cent.; from No. 3, fifteen per cent.; and from No. 4, five per cent. Tower No. 5 contains milk of lime, and tower No. 6 beds of lime. The nitric acid so produced is added to limestone, and the solution is then concentrated until the residue can be poured molten into canisters. This Norwegian saltpetre is almost anhydrous nitrate of lime, containing thirteen per cent. nitrogen. It is estimated that, with the lower prices for electric energy current in Norway, nitric acid can be manufactured at a cost thirty per cent. less than from Chili saltpetre. At present, the factory at Notodden is turning out from 3000 to 5000 tons of nitrate per annum, and this has been regularly produced since May, 1905.

E. Rossi, of Italy, proceeds in still another way. He obtains improved results by oxidizing the air under heavy pressure. The oxidation is brought about by an incandescent substance similar to the filament of a Nernst lamp, and the equilibrium-point is avoided by absorbing the burnt nitrogen oxides with concentrated sulphuric acid flowing constantly through the interaction-chamber. Among the Germans the great firm

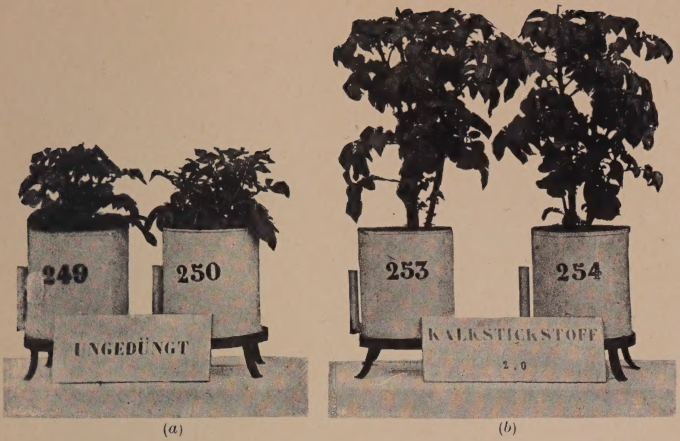


FIG. 10—CYANAMIDE AS A FERTILIZER FOR POTATOES

(*a*) Not fertilized (*b*) Fertilized with Kalkstickstoff

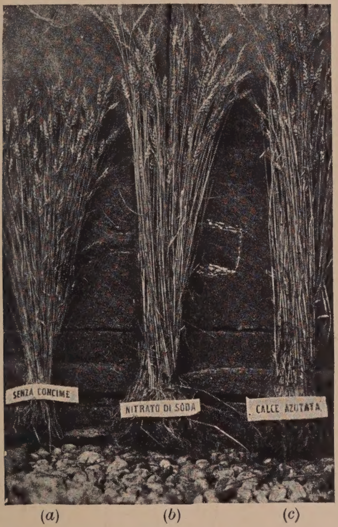


FIG. 11.—CYANAMIDE AS A FERTILIZER FOR WHEAT

(*a*) Without fertilizer.
(*b*) Fertilized with Chili saltpetre.
(*c*) Fertilized with Kalkstickstoff.

of Siemens & Halske has been intermittently busy ever since 1884, when old Werner Siemens sent a letter to his assistant directing him to experiment on the fixation of nitrogen. Dr. Georg Erlwein, who has present charge of this investigation, does not hold with the experiments just described. Instead of a multitude of intense little sparks of high-potential flaming arcs, he employs an arc formed by an enormous current at low voltage. He points out, and very truly, that increasing the size of these other plants will not increase their efficiency, while, in his own case, he finds that the greater the size of the arc he can form (the greater the unit in his factory), the greater is the per cent. of the nitrogen burnt. He has also provided against the easy decomposition of the burnt nitrogen into free nitrogen, by mixing the carbon of his huge electrodes with powdered fluor-spar, thus decreasing the temperature of the arc.

At present this firm is resting on what they have so far accomplished, and for a most significant reason. They have no more doubt than other people that they can profitably make nitric acid out of air and water, and at a rate concurrent with the present market price, but they are not satisfied with the market thus afforded, immense though it is. They demand the exploitation of the whole saltpetre industry as well, and nothing else will satisfy them. They deny that at present the electric nitre can compete with the natural product;

hence they prefer to wait until a little further advance in pure science brings it within their grasp.

Calcium is one of the few elements that have the power to unite directly with nitrogen. It is a silver-colored metal, which with comparative ease burns nitrogen, to form a nitride, and this nitride, on being thrown into water, yields ammonia and lime. Hence, if we could obtain calcium cheap enough, we could obtain ammonia cheap enough, and this would solve the problem of nitrogenous manure. Ten years ago this would have been visionary nonsense; to-day, were there no other means at our disposal, this is the very scheme we should quickly take measures to cheapen and adopt. Two years ago calcium was worth fifteen dollars a thimbleful; to-day it is worth about a dollar a pound, and its price might be greatly reduced.

It is a very common metal, because every bed of limestone contains nearly forty per cent. of it; in the past it was very rare because of the difficulties of its extraction. To-day, calcium is made by the ton, by decomposing the melted chloride of calcium by a current of electricity. The metal attaches itself to the cathode, and by slowly lifting the cathode a long "cabbage-stalk" of the metal is produced. Fortunately we do not need to worry over the still cheaper production of calcium, for, working in one of its compounds, this same metal has solved our problem in another way and with such success that it has temporarily thrown into secondary importance all the other processes we have so far considered.

Everybody has heard of calcium carbide, and of the bright illuminating gas, acetylene, which it evolves when thrown into water. The story of the carbide discovery, its manufacture, the fond hopes of the investing public that they could displace by acetylene the ordinary illuminating gas which the manufacturers could afford to sell for nothing, their disappointment, the revivification of the industry, and the latest phase of its usefulness, is a story of high romance and high finance. We are concerned here only with its latest phase.

It occurred to Professor Adolph Frank, of Charlottenburg, that the easy manufacture of carbides pointed out a way to the commercial fixation of nitrogen. In order thoroughly to test his schemes, he took refuge under the broad ægis of the restless, experimenting, progressive firm of Siemens & Halske, whose means and resources were adequate to every human purpose. At first he had in mind only the manufacture of cyanides, by passing atmospheric nitrogen over the heated carbide of barium and converting the cyanide of barium obtained subsequently into the most valuable of the nitrogen compounds, the cyanides of sodium and potassium. He was entirely successful in this operation; but, in order still further to improve it, he resolved to make a stubborn attempt to utilize the analogous carbide of calcium instead of barium, for it happens that it is not only cheaper, but much more efficient, weight for weight.

His attempt resulted in a complete surprise. He found, as a matter of fact, that atmospheric nitrogen reacted with red-hot calcium carbide in accordance with a little equation, which, with apologies to the lay reader, we shall insert:

$$CaC_2+2N=CaCN_2+C.$$

The result of the reaction is the complete conversion of the carbide into carbon, and into a substance which, while its name sounds something like the calcium cyanide expected, is wholly different from it—calcium cyanamide.

Next he discovered that this calcium cyanamide, on being heated with high-pressure steam, passed easily into limestone and ammonia, and finally he found that, on merely spreading out the material in the moist air, it slowly evolved this same substance, ammonia. This led him to the natural conclusion that the substance might be used as a fertilizer, and to determine the question he sent large quantities to Herr Geheimrat Professor Wagner, of Darmstadt, to Dr. Gerlach, of Posen, and subsequently to numerous agricultural stations scattered over the country.

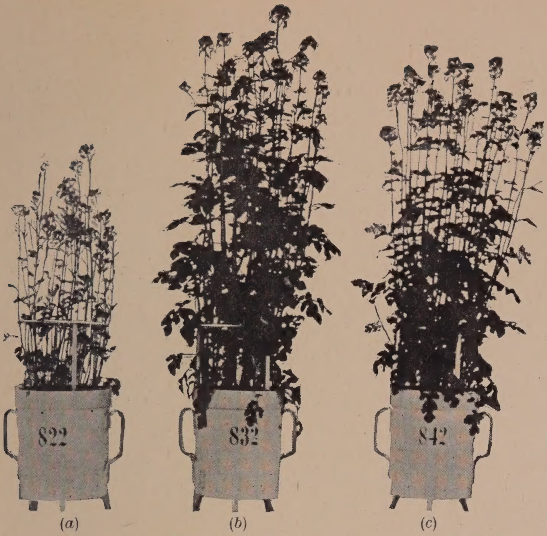


FIG. 12.—CYANAMIDE AS A FERTILIZER FOR MUSTARD

(*a*) Without fertilizer.
(*b*) Fertilized with ammonium sulphate.
(*c*) Fertilized with Kalkstickstoff.

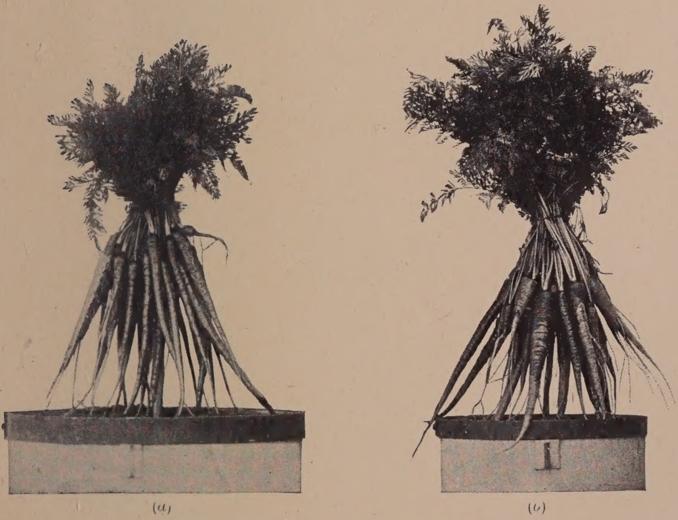


FIG. 13.—CYANAMIDE AS A FERTILIZER FOR CARROTS

(*a*) Without fertilizer.
(*b*) Fertilized with Kalkstickstoff.

The result of this experimentation has established beyond all question the fact that, under certain conditions, calcium cyanamide is a better fertilizer than the sulphate of ammonia from the gas-works, and practically equal to the saltpetre from the mines, weight for weight of the nitrogen that it contains. For the growth of wheat it gives its best results when buried four to five inches below the surface of the soil some eight to fourteen days before the seed is sown. The exact mechanism of its action has still to be determined. It is not unlikely that the calcium cyanamide in the soil breaks down into cyanamide itself, which in turn decomposes into ammonia, which oxidizes into nitric acid, and that the nitric acid so formed unites with the lime constituent of the compound to form calcium nitrate. Possibly, also, urea is formed in the process. However this may be, it is certainly efficient, and its utility, already great, is likely to be enhanced to an indefinite extent by the remarkable discovery of Dr. F. Loöhnis, of Leipzig, who has proved that nitrogen-loving microbes naturally occurring in the soil are able to eat it, and to produce in this way, at an accelerated pace, the free ammonia which the plants absorb. [Figs. 10 to 14 are examples of the effects of cyanamide as a fertilizer for potatoes, carrots, mustard, wheat, and oats.]

The world is now, thanks to Dr. Frank, in the possession of a fertilizing material that is almost ideal. The parent calcium carbide is made out of lime and coke which are everywhere cheap and available, and the atmospheric nitrogen anybody may use. The cheapness of the fertilizer is thus dependent solely upon the price of electrical energy. Even now, the fertilizer equivalent of an electrical horse-power is superior to the living horse. A living horse produces yearly some 21,230 pounds of manure, which contains about 126 pounds of nitrogen, while the electrical horse in the same time fixes no less than 550 pounds of this same nitrogen in the form of calcium cyanamide.

Under the name of "Kalkstickstoff," this calcium cyanamide is now in the markets of the world. The little experimenting Cyanid-Gesellschaft, which consisted of Siemens & Halske, the Deutsche Bank, and Professor Frank, has turned over the manufacture of Kalkstickstoff to a large company formed for the purpose, the Societa Generale per la Cianamide, of Rome, and this company in its turn consists of the Cyanid-Gesellschaft, the Societa Italiana per la fabbricazione di prodotti azoti, edi altre sostange per l'agricoltura, and the Societa Italiana per il carburo di calcio acetilene ed altri gas, of Rome.

In manufacturing the substance, they employ the latest results of technical science. The atmospheric nitrogen must be separated from the oxygen with which it is mixed. They, therefore, liquefy the atmosphere and separate the two substances by fractional distillation. The oxygen passes off to be used for other purposes, but the nitrogen passes suddenly from the intense cold of liquid air into the highest heat of the electric furnace, where, through contact with a mixture of coke and lime, it is caught and transformed into Kaltstickstoff.

The action of the Cyanid-Gesellschaft in turning over the fertilizer phase of Kaltstickstoff to the guardianship of another company has left their hands free to exploit its other uses. These uses are manifold. The fact that calcium cyanamide, under the action of high-pressure steam, passes over all its nitrogen into the form of ammonia leads to an excellent method of making this substance and other ammonium salts. The company has at present a demonstration-plant in operation for the production of 1500 tons of ammonium sulphate a year. But mixed with carbonate of soda, or with common salt, and fused, the cyanamide passes over into the form of cyanide of sodium, and this cyanide is useful for a vast number of processes, from silver-plating to gold extraction. They have a plant for this purpose, yielding 500 tons a year, and in Mexico, for mining purposes, they are beginning to manufacture the cyanamide directly at the mouth of the mine. A valuable use of cyanamide has been found in a curious function it has of causing the case-hardening of steel, and we find the great firm of Ludwig Loeve & Company, for one, continually using large quantities of it in the manufacture of tools and of arms for the government.

An interesting substance easily produced by the action of acids upon calcium cyanamide (with an apology to the reader for its hard name) is dicyandiamide—a beautiful crystalline body containing sixty-six per cent. of nitrogen. This substance, previously known only as a laboratory curiosity, is now made by the ton, and much of it is sold to the dye industries for a purpose that cannot be imagined by the manufacturers. Still other quantities are sold to manufacturers of explosives, owing to the fact that when mixed with other substances it lowers the temperature in the gun-barrel. A very interesting property of cyanamide is the ease with which it may be made to unite with water to form urea—a substance occurring naturally in animal excretions. Tons of this artificial urea are now sold to manufacturers of pharmaceutical preparations, though, again, for purposes of which the manufacturers of the urea have no idea. Guanidine, another product of the animal organism, is also made from it, and, we are informed, tons of it are now being sold to America.

Still another reaction, of no practical utility to-day, but impressively significant of a thousand utilities awaiting the hand of future man to develop, is that by which sarcosin unites with this same cyanamide from atmospheric nitrogen to yield creatine — one of the actual substances of human muscle found in extract of meat.

From all these facts it is demonstrated that we may

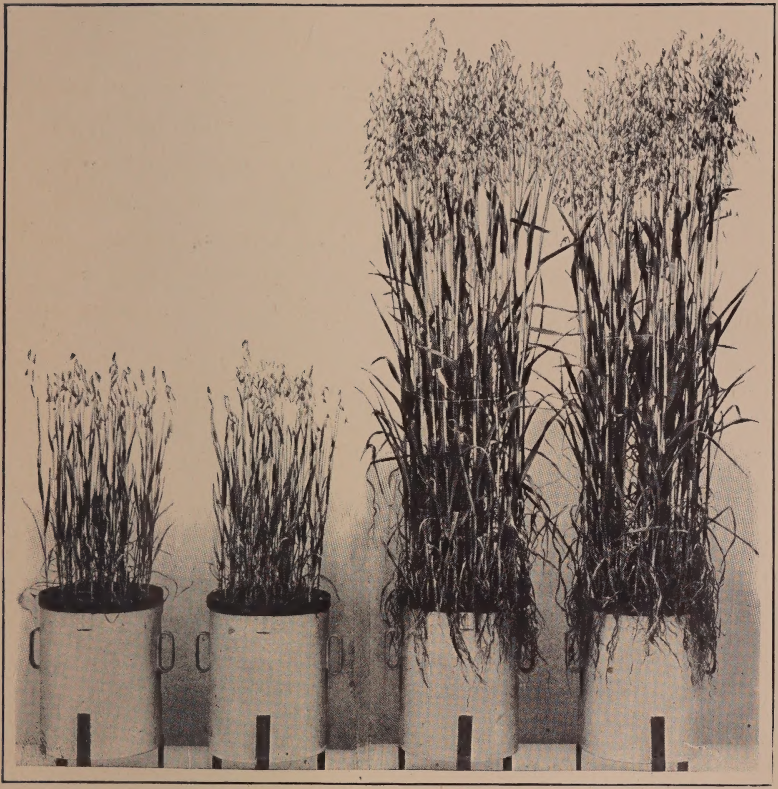


FIG. 14.—CYANAMIDE AS A FERTILIZER FOR OATS

(*a*) Without fertilizer (*b*) With fertilizer

look forward with a very reasonable assurance to the creation of as many factories for the fixation of elemental nitrogen as we have smelting furnaces for the unfixing of elemental iron. Through all these processes we see the unwilling nitrogen, fixed by the genius of man into the active and useful form, working not only in the thousands of nitrogenous substances used in our civilization, but in the soil, in the plant, and causatively in the actions and thoughts and feelings of men, until, freed of its energy, it sinks back into the Nirvana of the empty air. We see, too, that the disaster of which the world actually stood in imminent deadly peril has been averted, and that if every pound of saltpetre in the mines of Chili were suddenly to dissolve into its elements, the human race would still be able to guard itself against the unhumanity of nature. Though, is there this unhumanity of nature?

> "Say there be;
> Yet nature is made better by no mean,
> But nature makes that mean; so, o'er the art
> Which you say adds to nature, is an art
> That nature makes."

Every atom within us moves in harmony with every atom without, and we that *think* we move them to suit our needs or our caprice are but the crude instruments of a Purpose unfulfilled and unimagined, but predestinated from the beginning of all things.

The present-day practical lesson of this whole strenuous successful work lies in the little object-lesson it affords of the immense importance which technical science is assuming in our daily lives and in all our industrial operations. The substitution of real knowledge and high technical skill for the "rule of thumb" of our ancestors has created a revolution in industry. This revolution took its rise in Germany, and it is spreading rapidly to every corner. It is spreading silently, too, *because it does not pay to tell.* During the next five years the small manufacturer who is swept out of existence will often wonder why. He will ascribe it to the economy of large-scale operations, or business intrigues, or what not, never knowing that his disaster was due to the application of pure science that the trust organizations and large manufacturers already are beginning to appreciate.

IV

THE RARE EARTHS AND SOME OF THEIR APPLICATIONS: HOW SUBSTANCES OF MERELY ACADEMIC INTEREST MAY SUDDENLY ASSUME PRACTICAL IMPORTANCE

THERE is a certain question that almost inevitably proposes itself to everybody that studies chemistry: Why are some of the elements of matter so excessively abundant, while others are so excessively rare? Why is there one volume of oxygen in every five of air, while there is only one volume of krypton in twenty million? Why did Boisbaudran, in order to obtain some two ounces of the metal gallium, find it necessary to work over nearly 600 pounds of crude material, while the metal aluminum, which is not unlike gallium, we use in the commonest way? Why, in a word, is gold so hard to come by, while iron lies literally everywhere? Actually, more than half of the known elements are rare, unheard of by the layman and practically unknown to ninety-five per cent. of working chemists. Who, for example, has ever heard of, much less worked with, lanthanum, europium, erbium, neodynium, gadolinium, thulium, praseodymium, terbium, ytterbium, samarium, holmium, tantalum? Yet these forbidding names represent certain elements of matter just as do others, such as sulphur, phosphorus, or lead; elements, too, unique in their properties and filled with all kinds of potential usefulnesses to man.

If we could but answer the question why gold is rare and iron is common, we should probably have the answer to one of the most interesting secrets in all the world—the secret of the genesis of matter; for in order to answer it we should find it necessary to know, first, how gold and iron *came to be made.* Of course this secret lies carefully packed away in some of the hidden places of the earth, but there are certain paths of investigation indicated by which we may hope to arrive. For example, gold is rare and gold is heavy, and most of the rare elements are heavy, too. Is there not some significance in this? It used to be thought that gold, together with other rare elements, was rare *because* it was heavy—that when the earth was in a molten condition, gold and the heavy elements would fall to the centre, and hence that we should find upon the surface merely rare and accidental traces. This idea received support from the fact that the density of the earth, calculated from astronomical data, was markedly greater than the average density of the surface. We now know, though, that this difference in density may be accounted for by the influence of pressure at great depths. It is altogether unlikely that we should ever find a gold-mine by "digging down to China," for the apparent rarity of certain elements seems to be an actual rarity throughout the whole mass of the earth.

Another significant fact is the way in which the rare elements are associated together. Everybody knows that a lead-mine is always more or less a silver-mine, and a copper-mine a gold-mine; and to take another example of many, the dozen elements cited above as an example of rarity are always found together in a few rare minerals discovered in widely scattered localities. It used to be said that this curious association of certain elements was to be accounted for by the law that "birds of a feather flock together," and that owing to chemical similarities they became associated by the sorting processes of nature. Unfortunately, though, for the theory, many of the associated elements are not "birds of a feather" at all — silver is not like lead, and gold is anything but copper, in a chemical sense— and when we come to look for this "sorting process," there is no such thing ascertainable. It is plain that we must seek elsewhere for an explanation of the rare elements.

We are beginning to find a hint of the answer in the new knowledge initiated by Becquerel's discovery of the radioactivity. The possible explanations are two. The first depends upon the fact that the radioactive elements, such as radium, thorium, and uranium, possess the heaviest atoms we know in nature, and furthermore that the radioactivity of these elements seems to depend upon their actual disintegration into simpler elements. This is now a commonplace of the new knowledge. In addition to this, some of the elemental products of this disintegration are not themselves radioactive. May it not be, then, that gold and other rare elements with heavy atoms are the decomposition products of still other elements — rare because they are transient and break down into other things? It would not surprise us in the light of radioactivity to find that silver is always in lead because lead breaks down into silver. It has recently been suggested that all the silver should carefully be removed from some few tons of lead, and that after the lapse of a few years a fresh crop should be looked for.

The second theory insists that the converse is true, that instead of the rare elements resulting from a process of elemental decomposition they may result from elemental synthesis. The forty years' work of Sir Norman Lockyer has at last familiarized the world with the conception of an inorganic evolution in the sun and stars by which the heavy elements are synthesized out of the lighter ones, and radioactivity lends countenance to this idea by the statement that the lighter elements may be taking up as much energy to evolve into heavy elements as is given up by the heavy elements in disintegrating into light ones. On the basis of either explanation the rare elements are rare because they are transient—transition forms—unstable. There seems to be experimental support of this in the study of the rare earths. The dozen rare elements named above occur associated together, but in endeavoring to isolate them the results obtained depend upon the method employed. The amazingly contradictory results of the eminent workers in this field can best be explained by the assumption that these elements actually break down in their hands. They seem derived from one another, but whether Terbium begat Holmium and Holmium begat Erbium, or whether, on the contrary, Erbium begat Holmium and Holmium Terbium, we have no idea. We thus see two possible solutions for this problem, but no demonstrative answer. Down in the earth somewhere, "surely there is a vein for the silver and a place for gold where they fine it," but as for the question "Why is gold?" it is as insoluble as the question "Why is a hen?"

But if we cannot answer "Why is a hen?" we, nevertheless, all eat eggs, and although we cannot explain the origin of the rare elements we still may use them. It is the industrial use of a few of these rare elements that we make the subject-matter of this chapter. But the rare elements are very many, and since Industry married Science, since Cinderella became a lady, their applications are just as many. We must, therefore, limit our study of these things to one phase of usefulness —let us say, to the lighting of our streets and homes.

Our chapter will serve to demonstrate in this way, better than in any other, the world of difference between the New Industry and the Old Industry, between the sway of the finger of Science and the ancient rule of Thumb.

Early in the eighties of the last century Dr. Carl von Welsbach was investigating the elements of the rare earths. In these investigations the spectroscope plays a most important part when brought to bear on these substances when raised to vivid incandescence. In order to increase this valuable incandescence a certain idea dropped into von Welsbach's mind—dropped almost from nowhere. This idea was the savior of an enormous industry. It occurred to von Welsbach that he might increase this incandescence by impregnating a piece of cotton with the substance and burning it in a bunsen flame. It certainly did increase the incandescence, but it did more. The organic matter of the cotton burnt away and left a perfect image of its fabric composed of the oxides of the elements taken, and the oxide skeleton glowed in the bunsen flame with a brilliancy and a beauty that were astonishing; this was peculiarly the case with the oxide of the element lanthanum. As a necessary consequence the idea entered his mind of using a cotton fabric impregnated with lanthanum oxide for practical lighting—the idea of a gas-mantle. With the interesting history of his attempts we have no space to deal.

He discovered that of all the rare elements, the oxide of the element thorium, thoria, was most efficient. Next, he discovered that the purer the thorium the less light it gave, and that the brilliant light of the mantle must be due to some interaction between the thoria and some impurity unknown; this was finally determined to be ceria. To-day, as the result of an amount of work hardly surpassed in the annals of science, there stands as the composition of every gas-mantle the following formula, which the thousands of attempts that have since been made have failed to improve upon: thoria, ninety-nine per cent.; ceria, one per cent.—total, 100.

How to explain the wonderful power of light emissivity awakened in the thoria by this trace of ceria has been a matter of endless controversy. The mystery deepens when it is discovered that although by weight the proportion of ceria to thoria is 1:99, by volume it is only 1:999.

The cotton with which the oxides was impregnated turned out to be unsuitable because its ash contained alkalies, which in the heat of the flame attacked and ruined the thoria. A systematic search through the fabric-making materials discovered ramie, or china-grass, which was almost ideal for the purpose, and which is now grown in India and southern Italy for the gas-lighting industry. The china-grass for any one mantle weighs some seven grams, and yet it contains only one-half of a milligram of ash, and this is pure silica free from alkali. It is woven by firms organized for the purpose into "stockings" of the shape and pattern which the reader may see above his head (Fig. 15). Thence they pass into the hands of the manufacturers of the gas-mantles proper.

While the natives of India have been collecting china-grass, and while it is being transported and eventually woven into "stockings," other people of a wholly different character and race have been digging out of the ground in Brazil a curious mineral called monazite sand. This mineral contains a dozen (and very many more) very rare elements mysteriously and almost inextricably mingled, but among them there are the thorium and cerium that we need. The mineral is found also in Florida and California, but it is not so good. It is now carried to the centres of civilization, where it is purified as rigorously as the methods of science permit; for while the thoria demands its one per cent. of ceria, it insists on nothing more. Every reader will remember the bad, greenish, eye-afflicting light of the early mantles. This bad light was due chiefly to the presence of the elements orbium and ytterbium, which are now most carefully eliminated. Finally, as the nitrates of practically pure thoria and ceria they enter one door of the gas-mantle factory while the china-grass "stockings" enter another, and here their history begins. The first operation consists in dipping the china-grass stocking into a properly constituted solution of the thorium and cerium nitrate.

The stocking is then passed through a wringer, so that only the requisite quantity of the solution remains. It must then be dried. But if it were merely hung up to dry, the solution would run down to the base and disaster would surely result. To obviate this, the stocking is slipped over a glass form, which retains the solution *in situ* so that when dry there is a uniform distribution of the thorium-cerium mixture. Next it must be strengthened at the top, for the gas-mantle is so frail that, otherwise, it would never support its own weight. For this reason the dried mantle is now taken to another room, where its upper end is dipped into a solution of the oxides of beryllium and aluminum, which, when heated, forms a strong glass. The next requisite is a method for suspending the mantle over the burner. This is furnished by drawing the top together and forming a loop with a thread of long-fibred asbestos made in Belgium. At this stage of the operation the manufacturer satisfies his natural desire to advertise the superexcellence of his ware by painting a label on the mantle. This is done with a solution of uranium nitrate so that in the heat of the burner his name will appear in the effulgence of the mantle.

So far the shape of the mantle-stocking is crude and imperfect, and it is now moulded in a wooden form to the shape it is to assume in the lamp. Up to this point it is a mantle-stocking woven of china-grass impregnated throughout with the nitrates of thorium and cerium, at the top with beryllium and aluminum, and in spots with uranium. At this point the transformation occurs. The mantle is placed in the intensely hot flame of a pressure gas-burner, and in an instant what was a woven cloth is now the delicate fabric of a gas-mantle. The cloth has disappeared in a whiff of flame, the nitrates have become the incandescent oxides, preserving with marvellous fidelity the delicate filament of the original pattern and glowing with unexampled brilliancy. There is but one thing more to do. It must be strengthened to endure the jolting transport of the hundreds of miles from the factory to the home, and this is accomplished by dipping it into a mixture of copal, shellac, alcohol, ether, and camphor, and subsequently drying it. The mantle is finished, and finished it is what every manufacture *ought* to be—the product throughout of scientific skill and knowledge.

The sudden chance thought of von Welsbach, that of dipping a piece of cotton in his rare-earth solution, has created a powerful industry full-armed in defence of gas. It is impossible to doubt but that years ago illuminating gas would have succumbed to its electric rival without this aid. In Germany alone over one hundred and fifty million gas-mantles are manufactured every year, and the total number manufactured the world over staggers belief. To manufacture these

German mantles over 330,000 pounds of thorium nitrate are employed, 120,000 of which come from Brazil through the hands of a monopolist, Herr de Freitas, of Hamburg. Millions of money and thousands of men are employed in the utilization of a rare mineral which a few years ago had nothing but an academic importance.

In calling the rare earths the savior of the gas in-industry we had in mind as the rival of gas only the incandescent electric-light bulbs containing carbon filaments, such as we see everywhere around us. We left out of account that while these rare earths were sauce for the goose they might likewise be sauce for the gander. It was in 1897 that Professor Nernst, of Göttingen, showed that while at ordinary temperatures a pencil or filament made of these rare earths was a nonconductor of electricity, it required only the application of a lighted match to render it a very good conductor indeed, and that the hotter it became the better a conductor it was.

It is very like one of the Holland dams. So long as the dam is perfect the dam is safe — it is a nonconductor of water—but permit the smallest hole, no larger than a finger, upon which the water may work, and, shortly after, the resistance of the dam has broken down, and the whole volume of the current washes through. The cold filament made of these earths offers an impenetrable resistance, but at 600° C. a little current passes. This makes the filament hotter, which allows more current to pass, which make the filament still hotter, which permits still more current, which makes the filament hotter again, and so it builds itself up until it arrives at a semi-pasty condition when practically the whole of the current passes through, and it shines with a very vivid and very beautiful incandescence.

This is the basis of the Nernst lamp (Fig. 16), of which tens of thousands are now being sold in America. It is the only incandescent electric light that burns in the air and can be lighted with a match. Essentially, it seems a simple affair, but there are many complications which rendered its development a matter of extraordinary difficulty. It has taken the Algemeine Elektricitäts Gesellschaft, together with its allied or subsidiary companies in America, France, and England, some six years of ceaseless effort to secure their present lamp. Think of the difficulty, for one thing, of squeezing an earthy powder into an exceedingly strong, hard thread. In its present form the Nernst lamp is, necessarily, a complicated mechanism. The fundamental part of the lamp, the thread, is made of practically the same substance as the incandescent gas-mantle, thoria, though some filaments contain almost pure zirconia. This is surrounded by a coil of iron wire, and the lamp is so made that on switching on the current it passes first through the wire, which becomes red hot. The heat of the wire initiates the conductivity of the rare-earth filament, and so soon as it begins to do this the current passes at the same time through a little electro-magnet hidden in the body of the lamp, which actuates a spring that cuts the iron wire altogether out of the circuit and permits the whole body of the current to pass through the filament (Fig. 17).

It is very pretty, the way in which it does this, and the reader will probably notice that it is something like a minute after the current is switched on before the action is complete and the lamp shines out. But unfortunately this is not the whole lamp. The fundamental fact in the Nernst lamp is its greatest weakness. We have said that the hotter the filament is the more the current goes through, and of course the converse is true, the less the current the cooler the filament, and the cooler the filament the less the current. Now no electrical current is perfectly steady, and, consequently, the lamp as so far described would be quite impossible of practical application. There would be too great a variation in light, too great a variation in current, and in consequence of the mechanical shocks to the filament resulting from these variations in current, too short a life to the lamp. They found it necessary to introduce a complicated steadying resistance to compensate for this unfortunate fact. To-day one of the marvellous things about the Nernst lamp is the compactness with which all this complicated mechanism is arranged in the small body of the lamp.

The advantage of the Nernst lamp is this, that it gives a beautiful light which is fully fifty per cent. greater per unit of electrical power than the ordinary carbon-filament lamp that we see in everybody's house, and this advantage much more than compensates for the increased cost of the lamp. The disadvantages are that seemingly the lamp is really good only for alternating currents, and the character of the current must be strictly defined, and, moreover, owing to the fact that the compensating resistance does not really compensate, a comparatively short life to the compensating part of the lamp and to the filament. Besides, there is the complication of it. Still, the Nernst lamp is very successful, and we may see its beautiful radiations competing with its gas-mantle brother in almost every town in the land. In Germany no less than 4,000,000 Nernst lamps have been sold.

The Nernst lamp not only accentuated the war of gas *versus* electricity, but it initiated an internecine strife within the electrical camp. Up to that time electricity had been content with carbon filaments. On the coming out of the Nernst lamp, however, von Welsbach, who had been the champion of the gas industry, joined forces with its rival. He has devised a lamp which for beauty of light, efficiency, and length of life is not at all unlikely to throw all pre-existing forms of illumina-

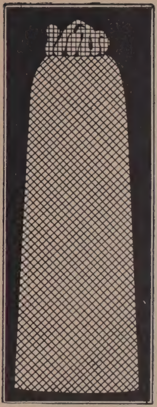


FIG. 15.—THE FAMILIAR GAS-MANTLE

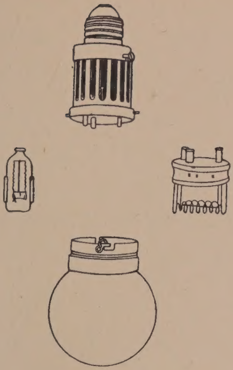


FIG. 16.—THE NERNST LAMP

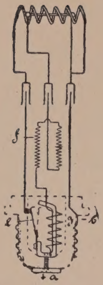


FIG. 17.—PATH OF CURRENT IN THE NERNST LAMP

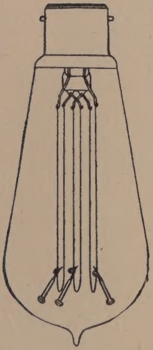


FIG. 18.—THE OSMIUM LAMP

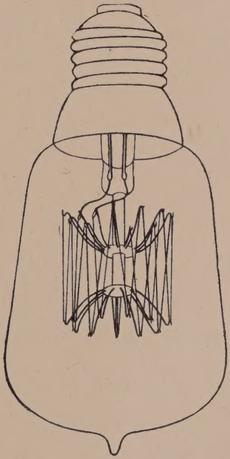


FIG. 19.—THE TANTALUM LAMP

tion literally into the shade. It resembles the ordinary vacuum bulb containing a carbon filament, with this difference, that the filament consists of pure metallic osmium.

This osmium is a very rare element, found generally associated with platinum, which it much resembles. In its crystalline form it is a bluish substance, 22.4 times as heavy as water, and it is probably the most refractory and unalterable solid known to science. The metal is not only difficult to obtain in quantity, but many difficulties are connected with its extraction, and even dangers, for the osmic acid readily formed is poisonous and produces permanent blindness. It is this metal which is used as the conducting filament in the lamp represented in Fig. 18. In order to obtain the filament a platinum wire is coated with the osmium *and the platinum is then volatilized away.* The hair-like filament thus forms a tube.

The advantages of the lamp are manifold: It gives a light beautiful in color; it saves no less than fifty-six per cent. of the electrical current; it is, unlike the Nernst lamp, but little affected by changes in the current; it has an extremely long life, say 2000 hours; and there is no blackening of the bulb owing to the disintegration of the filament, as with carbon. On the other hand, its cost is high and, apparently, it can be used only on a current of about fifty volts, which is awkward. Again, the osmium filament is so exceedingly fine and threadlike—hairlike, rather—that it is fragile, and the lamp must be burned in a vertical position. One of the main difficulties that this company has to contend with is the breakage of the fragile filament during transportation. If the company can strengthen the filament, which is likely, and can decrease the initial cost, which is doubtful, it will almost certainly relegate the Nernst lamp to the museum.

The idea of using a metallic filament in place of carbon did not occur only to von Welsbach. Particularly did it occur to Dr. Werner von Bolton, the chief of staff in the laboratories of Siemens & Halske, of Berlin. Von Bolton devoted seven years to the task of finding a metal suitable for use in electric-light bulbs. He had no guarantee of success, he pursued a vision, but as is so often the case, his importunity brought him his reward. Even since 1803 chemistry has known of a certain rare element found in just two or three places in the earth's crust, almost unacted on by other bodies, and called tantalum, " because even when in the midst of an acid it is unable to take the liquid to itself."

In the form of various compounds chemists became very fairly well acquainted with tantalum, and they thought, but only thought, that they knew the pure element. It remained for Dr. von Bolton to show that this was a cardinal error, that their so-called tantalum was an impure product, possessing properties widely different from the element itself. He obtained his tantalum in a novel but simple way by placing the oxide of the element between the poles of a powerful electric arc, under the intense heat of which the oxygen is expelled. Now, if this were done in the air as much oxygen would unite as was expelled, and the experiment would be no forwarder, so he employs a vacuum and pumps off the oxygen as fast as it is formed. Thus, the oxide of tantalum is rapidly reduced to the pure metal *if* the poles of the arc are tantalum itself. We have italicized this *if* because originally, using platinum electrodes, he was led into error—a thing mislikable to chronicle; but, since a scientific man must stand for what he says, here it is: According to the first experiments, tantalum was so hard that "it was found impossible by means of a diamond drill to bore a hole through a sheet one millimetre thick," even though the drill rotated 5000 times to the minute for three whole days. It turned out that the reason for this was that the tantalum was still slightly impure, and that this impurity vanished on employing an arc formed between electrodes of the tantalum first made. This first tantalum is thus the ancestor of all the free tantalum in the world to-day.

As a matter of fact, tantalum is just about as hard as the very hardest steel; it is unaffected by almost all reagents; at ordinary temperatures it is absolutely unrustable; its fusing-point is exceedingly high, about

2300° C.; it may be rolled into the thinnest of thin sheets, and drawn into the finest of fine wire; and in reheating the hardness becomes extraordinarily increased. Its high fusing-point realized for Siemens & Halske their electric lamp, which forms, perhaps, the most beautiful light known to man. In the lamp (Fig. 19) the length of the filament is no less than twenty inches — a bothersome thing to pack in the bulb; and yet so fine is this wire that one pound of the metal will manufacture 20,000 lamps. The efficiency of the lamp is more than twice that of the ordinary light-bulb; its length of life is extraordinary; the filament is, unlike that of the osmium lamp, strong and durable; and it may be used on the 110-volt circuit. Were it not for the fact that it does not do well on an alternating current it would seem a peerless instrument for the lighting of our homes.

The present high cost of the lamp is not inherent, for, according to Dr. von Bolton, its price is established simply to limit its sale until the firm is ready to supply the market of the world. The quantity of tantalum available is much greater than was anticipated, for deposits of columbite, its containing mineral, originally found in South Dakota, have been supplemented by much richer masses in Australia, and the company will now accept only mineral containing a generous proportion. There is so much of the mineral that they now propose to manufacture small tools and other articles.

For hardness, unalterability, ductility, and malleability, the element tantalum will thus constitute a sublimated steel; and since with this company it is a word and a blow, their tools may soon be expected on the market. In the mean time the tantalum lamp, clothed with light as with a garment, may be seen in all the great cities of the world.

A lamp, still more recent, is the tungsten lamp, which utilizes the light evolved through the resistance offered by fine filaments of the metal tungsten. The tungsten lamp gives a light delightful in color and perhaps unrivalled in efficiency. Its disadvantages are that owing to the resistance factor of the tungsten the lamp is awkwardly large, and owing to their brittleness almost untransportable through long distances. Still another is the helion lamp, devised by Professor Parker, of Columbia University. This lamp depends for its light on the ordinary carbon filament, upon which is superimposed a thin layer of the element silicon, which is apparently united chemically with the underlying carbon. While the light of this carbon-silicon filament is unquestionably highly efficient, its other factors have still to be demonstrated. A wholly new and remarkable form of lamp, recently devised by Professor Parker, is one which is intended to withstand heavy jars, or which is intended to last indefinitely in almost unattainable stations, such as on the ceilings of high buildings. It consists of a fine quartz-tube, packed with refractory and resistive material, such as the rare earths; into each end of the tube passes an electrode, and the switching of the current renders the intervening rare earths incandescent. It is proposed to use these novel lamps on the heavy guns in the navy, for, obviously, no shock, however great, could break them.

These are a few of the rare elements as they are applied to one problem only, the lighting of our streets and homes. Of course, the lighting industry does not confine itself to the rare elements only. The whole industry is saturated with the scientific spirit, and it appeals to everything under heaven for "more light."

There is, for example, the Cooper Hewitt lamp, or, in its developed and improved form, the Bastian lamp. This lamp shines by the incandescence of mercury vapor. Its economy is almost unprecedented, and its length of life is indefinitely long, but its color is—a green impossible! Then there is the "Nürnberg licht," a gas-mantle vivified by the combustion of illuminating gas and pure oxygen, and depending for its supremacy upon the price of oxygen, which, according to current rumors, is likely now to sink to a cost beyond their fondest expectations. Again, there is the "flaming arc," an open arc lamp whose carbons contain metallic salts such as calcium fluoride and potassium silicate. This lamp is, confessedly, in the golden beauty of its light and in the small demands it makes upon the electrical current, the champion of the street, and it is a pity that owing to its poisonous vapor it cannot be used in our homes. Finally, there is the necessary, absolutely necessary, counter of the carbon-lamp industry to all these stings and arrows. They have announced a graphitized carbon filament with the chief advantages of the metallic filament we have already considered; but for these lamps we must wait to see.

An evening walk down Piccadilly, or the Friedrichstrasse, or the Avenue de l'Opéra is illuminating not only to the eye of sense, but to the eye of the mind. All these lamps are burning there, and letting their light so shine that he who runs may read the lesson of the times. This lesson is just *efficiency,* the efficiency that depends upon the knowledge and skill which is modern science, and which is good not for light alone, but for every industry known to man.

V

HIGH TEMPERATURES AND MODERN INDUSTRY: WHAT ATTAINMENTS MAY RESULT FROM CARRYING TO EXTREMES THE ACTION OF ANY AGENT

FOR the greatest discoveries of Science, attainment lies, in these days, in one or two directions—either on the border-line between one science and another, or by carrying to extremes some one principle of investigation already well known.

For the first method, compound sciences, such as physiological-psychology, physical-chemistry, or physiological chemistry, are, in these days of their triumph, sufficiently significant; for the second, no one principle of investigation better illustrates it than the effect of temperature upon chemical action. Consider between what small limits of temperature lies the possibility of life—a few degrees below freezing or a few degrees above, and we arrive at the lethal-point. Animals and the results of animal-work lie absolutely within these few degrees. But with man it is different; he discovered fire, and the powers of fire, and this discovery properly marks the point at which he became a man.

Beginning with leaves and brushwood, he has passed progressively up through "the good beach cole" of the alchemists, which gave the highest attainable temperature of the time, to coal and gas and the forced draught, until the world is darkened with the smoke of his chimneys. But while he has thus enjoyed enormous satisfaction from this increase in his powers, he has by no means reached the limits of temperature applicable to industrial use and, hence, the limits of his industrial powers. All the way down to that mysterious point called the absolute zero, which is apparently the lethal-point of heat itself, and all the way up, hotter and hotter and hotter, to some illimitable point of hotness that we cannot yet place, he has his chance.

With the lower temperatures we have in this chapter nothing to do, but with the higher we propose to demonstrate the application of a general principle of human progress, that when man carries any one of the agents of his civilization to the extreme of its power, he takes steps that may carry him over the threshold of the field of exhausted effort into new fields filled with a wholly new flora of useful products and untrodden paths of new processes and new methods.

The highest temperatures reached in fuel furnaces for technical purposes lie between 1700 and 1800 degrees on the Centigrade scale; they reach their limit at the melting-point of fire-clay and porcelain. The first step-up beyond this point lies in a flame fed with mixed oxygen and hydrogen, or with mixed oxygen and coal-gas. This flame has long been known in the familiar lime-light of the stereopticon. By its means a temperature of 2000° C. may readily be obtained, and we thus pass the high-water mark of regular industrial practice. Leaving its old utilities, let us discover what contemporary effort has done with it.

We must distinguish in this connection between the words "artificial" and "imitation." The shop windows of a certain character along the great streets of the world are flamboyant with the vulgar and tawdry representations of the precious stones. To the direct glance of knowledge they are no more the rubies, emeralds, or diamonds of the mines than are imitation flowers the lovely gifts of our garden. They are imitations, gross and palpable—gems of paste for pasty faces. We speak now of the "artificial" ruby, the ruby of science, which is as much the ruby of Ceylon or Burmah as is the water formed by burning hydrogen the water of the rain—identical in property and composition. The natural ruby of the mine consists of pure alumina, with a trace of coloring matter in the form of an oxide of chromium or manganese. The problem of manufacturing veritable ruby was, therefore, simply that of melting thoroughly together these simple things, a problem at first impossible of solution, because the melting-point of alumina lies above the limit possible of technical application. But the man and the means arrived with M. Verneuil and the oxyhydrogen blow-pipe. To-day, as the result of these two factors, there is to be found in the little factory connected with the shop of M. Pasquier, of the Rue Lafayette, in Paris, the commercial production of artificial rubies, and the consequent decree of doom to the ruby-mine, a doom which is now as inevitable as that of the alizarin industry of France or the indigo industry of India. The commercial synthesis of the ruby is illustrative of the intelligence and efficiency that govern industries of a modern scientific origin.

We begin with a solution of common alum, to which a trace of chrome alum is added as the ultimate coloring constituent. Now add ammonia, and there results a gelatinous precipitate of the hydrates of aluminum and chromium. This gelatinous precipitate is filtered off, evaporated down to dryness, and subsequently calcined into an intimate mixture of alumina and the oxide of chromium. It is then ground into an impalpable powder, and placed in the transforming apparatus, of which we give a diagrammatic representation in Fig. 20. Through the tube marked *A* passes a supply of coal-gas, through that marked *B* a supply of oxygen. The two meet at *C*, where they are ignited, and constitute a carefully regulated flame whose temperature is practically 2000° C. In the box at the top, marked *D*, is placed the powdered alumina, and the bottom of this box consists of a fine sieve. A small automatic tapper *(E)* carefully jars the powder through the sieve and through the tube, which, it will be observed, is the tube which serves for the supply of oxygen. It thus happens that every trace of the powder *must* pass through the flame of 2000 degrees.

It is so finely divided that it fuses as it falls upon the little stand marked *F*, where, within the outer influence of the flame, it gradually builds itself up into a beautiful ruby pear-shaped body, called the "brut," which is illustrated photographically and in its actual size in Fig. 21. This ruby pear, when one takes it in his warm hands, flies instantly to pieces. It is like the "Prince Rupert drops" in a condition of high strain. Once, however, this strain is neutralized by the breakage, the resulting fragments will break no farther, and it remains, now, only to send them to the gem-cutters, whence they return as ruby gems, which in glowing beauty of color, pellucidity, refractive index, hardness, durability, and chemical composition are identical with the natural ruby of the mine. So absolute is this identity, that the usurers of the great cities now refuse to take rubies in pawn, for they cannot distinguish. While the law ordains that they shall be differentiated from natural rubies by some distinguishing appellation, their use in jewelry is enormously widespread. This is shown by the fact that in the little "two-by-four" factory of M. Pasquier, alone, no

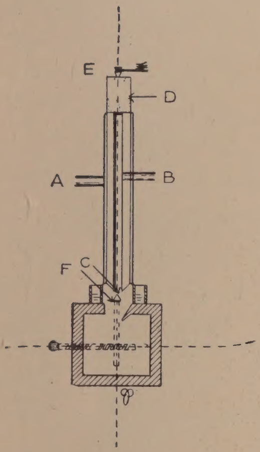


FIG. 20. — DIAGRAMMATIC REPRESENTATION OF A FURNACE FOR THE PRODUCTION OF RUBIES

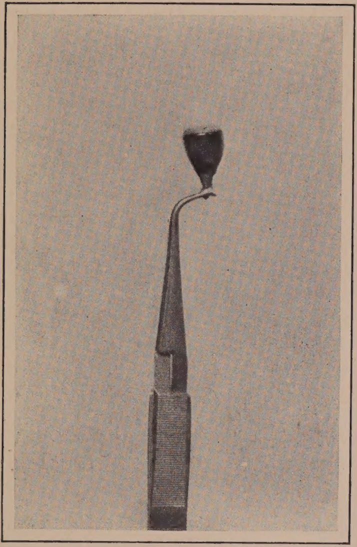


FIG. 21.—THE RUBY "BRUT"

less than 100 carats may be manufactured every day. The ruby-mines on their present basis of profitable working are absolutely doomed. Indeed, we might have known it long ago: "For Wisdom is better than rubies; and all the things that may be desired are not to be compared to it." And again, with a wider application, "I Wisdom dwell with prudence, and find out knowledge of witty inventions."

These "witty inventions," based upon the high temperature of an oxygenated flame, are by no means wholly destructive in their operation upon established industries. It is a most useful agent, is an oxygenated flame. For example, this flame of 2000° C. is above, but just above, the melting-point of quartz. By its use, and by the subsidiary aid of a common wooden bow and arrow, there have come to us the microscopic quartz fibres which are so useful as "suspensions" in the fine instruments for electrical mensuration. The quartz is melted in the oxyhydrogen flame, and the blunt end of the arrow is then dipped into it and suddenly shot from the bow. After that it is merely a matter of a magnifying-glass to find the resulting thread on the floor—a most "witty" and useful invention.

Again, the fact that the oxyhydrogen flame will melt quartz has resulted recently in a new industry, by which the quartz is built up little by little into tubes, flasks, and other chemical apparatus, for the use of which chemistry is incalculably indebted to industry; for these quartz vessels are inert to most operations, they may be heated many hundreds of degrees higher than glass, and, most blessed boon, even while white hot, they may be plunged with impunity into cold water. We shall refer to these valuable articles in another connection.

But the oxygenated flame has a utility wider still. As everybody knows, placing the "blower" on the grate increases the per cent. of oxygen passing over the fuel in a given time; it is the principle of the forced draught. But enormously better results may be obtained in another way. Since combustion depends upon the twenty-one volumes of oxygen in the air, why not increase its per cent. by abstracting the inert and diluting nitrogen? This is being done to-day in two distinct ways. The first depends upon the use of liquid air. The boiling-point of its constituent nitrogen is above that of its oxygen, and, hence, as its evaporation proceeds, it leaves a liquid continuously richer in oxygen. Not only so, but Pictet and others following him have devised a "separator," by which the evaporating gases separate, because of their different specific gravities, in such a way that nitrogen passes off through one tube and oxygen through another. This method is one of completely demonstrated efficiency; it is attracting wide attention in France, and it may safely be predicted that in a few years it will enormously increase the output of the unit blast-furnace and high-temperature steels.

The other method is a most curious one, and depends upon the hitherto unsuspected fact that it is possible to use centrifugal force in order to separate out a mixture of gases. The idea that with a revolving wheel it is possible to whirl out of the air nitrogen to one corner and oxygen to another seems almost absurd, and yet it is apparently capable of practical application.

The "Mazza Separator," as it is called, contains a centrifugal wheel, which, revolving in the air at speeds from 1200 to 2200 a minute, is capable of concentrating the per cent. of oxygen at the periphery. According to the experiments of Professor Schaefer, of the Technical School at Charlottenburg, the apparatus increases the per cent. of oxygen in the air drawn from the periphery from twenty-one volumes to twenty-six. Again, according to an Italian firm of paper-makers, who applied the separator to air furnished to their Cornish boilers, they saved throughout a month's working no less than 27.7 per cent. of their coal. Of course, it is capable, also, of whirling hydrogen out of illuminating gas, and so increasing its luminosity; of whirling carbonic acid out of waste blast-furnace gas, thus making it more available for the new blast-furnace engines; and, in fact, if its actual industrial practice yields even a modest approximation to the enormous claims of its manufacturers, its use ought to result in striking economies in furnace practice.

We see, so far, that even a slight increase in temperature above that of current industrial practice leads to new products and new methods. If we go a step higher we shall see this difference accentuated.

The industries of the world use for fuel only carbon and the compounds of carbon, but other substances may be used instead. This was discovered by Professor H. Goldschmidt, of Essen, in the use of aluminum for the production of heat. The difficulty of extracting this metal from its ores lies in the extreme unwillingness of aluminum to part with its combined oxygen. The two elements can be separated only by the application of an immense amount of energy, and this energy is, and must be, given back again when the aluminum reverts to its combined condition. This is the essence of aluminothermics. The innocent-looking mixture which lets loose this energy in a small time and a small space is called "thermit." It consists in its usual form of granulated aluminum and oxide of iron; the aluminum wants oxygen and the iron has it to spare, and there thus lies in the mixture the tendency to an instant and powerful reaction in accordance with the following little equation:

$$\text{Aluminum} + \text{iron oxide} = \text{aluminum oxide} + \text{iron.}$$

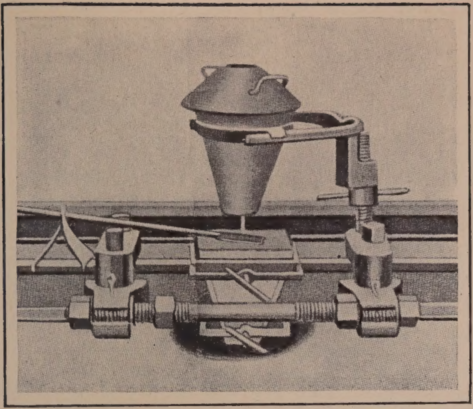


FIG. 22.—COMPLETE WELDING OUTFIT FOR THE USE OF THERMIT

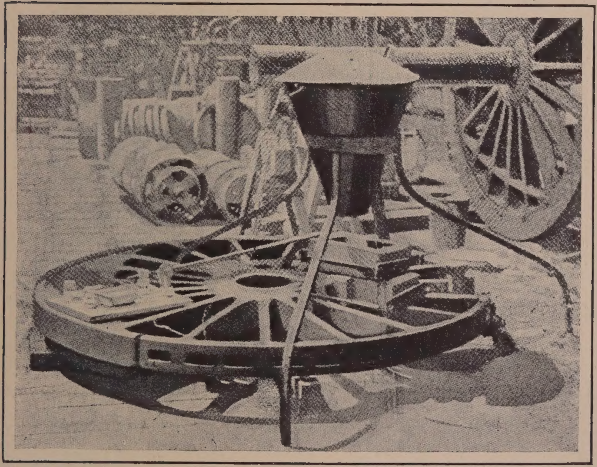


FIG. 23.—REPAIR OF DRIVER OF LOCOMOTIVE BY THE USE OF THERMIT

All that is required is a " trigger " to start it, and this is provided by placing on the top of the mixture as it lies in the crucible a small quantity of magnesium filings mixed with barium peroxide, a mixture that acts like the phosphorus in a match. Now, *very gingerly,* throw a lighted storm-match into the crucible, and in a fraction of the time it takes to tell it there lies in the bottom of the crucible a mass of molten iron, almost boiling—iron whose temperature approximates 3000° C.—fully a thousand degrees higher than any temperature in current industrial use, while on the top of the iron lies a slag of the oxide of aluminum, veritable corundum.

This reaction has received an extraordinary welcome at the hands of practical men. Its applications may, roughly, be divided into two classes—one concerning the engineer, and the other the metallurgist. For the engineer, the temperature is so high and the operation is so simple that whenever he wishes, say, to weld together two pieces of iron (an enormous field of utility), he may accomplish it, and accomplish it perfectly, by the intelligent use of this ideal method. For example: by this method has resulted the *continuous rail* — a necessity of the modern trolleys—and although it was introduced only in July, 1904, nearly every city in the United States is now using it (Fig. 22). Another field of application equally large lies in *the repair of solid iron and steel objects.*

Fig. 23 and Fig. 24 are eloquent; and we are not astonished to know that car-load orders for thermit were received from Port Arthur, or that it has, almost instantaneously, been adopted in most of the great workshops of the world.

For the metallurgist, the uses of thermit are as varied and as valuable as for the engineer. Thus, in foundry practice, the addition of a form of thermit containing titanium increases the fluidity of the cast iron, produces a finer grain, and increases the strength. It is used in the production of nickel-iron alloy, for reviving dull iron, for preventing the phenomenon of piping in making steel ingots, and in many other ways. But the utility of the reaction does not lie only in the production of this high temperature. Instead of oxide of iron, other metallic oxides may be used, with the resulting production of pure metals *free from carbon*—a matter of extreme importance to metallurgical industry. Thus the reaction, chromium oxide + aluminum = aluminum oxide + chromium, yields pure chromium, which is invaluable for the manufacture of guns, projectiles, and tool steels. Similarly, pure manganese is obtained, unrivalled in its use for very hard steel for bolts or for the value of certain of its alloys with other metals. Titanium, molybdenum, and vanadium are other metals produced in similar fashion and analogously useful each in its own way. Not only so, but the reaction is, to-day, being extended to compounds

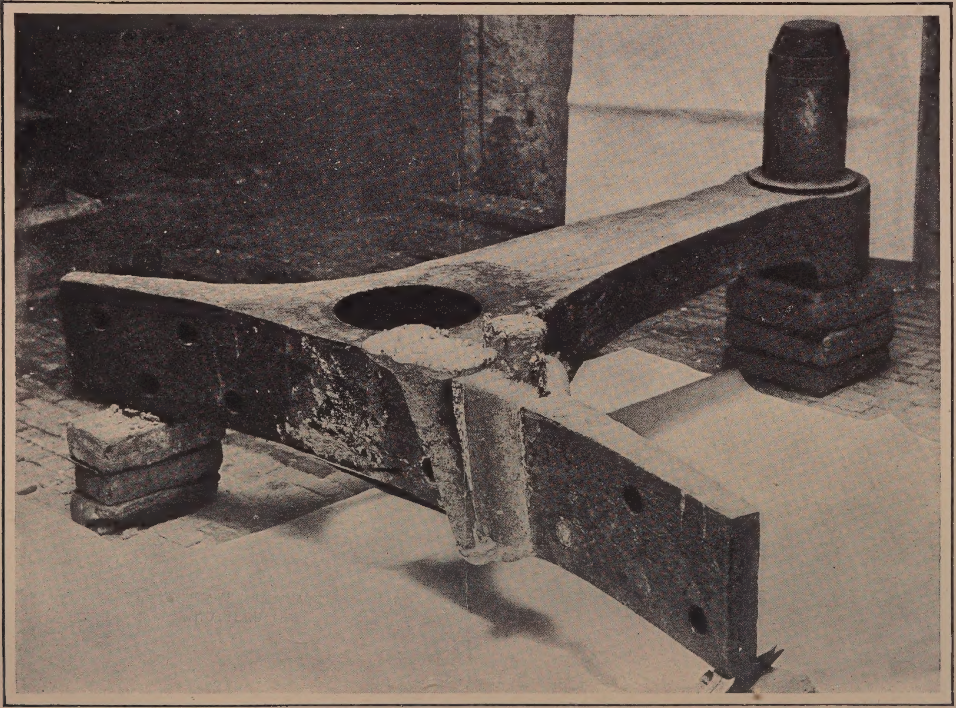


FIG. 24.—BROKEN PADDLE-SUPPORT OF FLUSHING STEAMER "ZEELAND," REPAIRED BY MEANS OF THERMIT

other than oxides with interesting and significant results.

Altogether, it may be said that with Goldschmidt's thermit, and the step-up in temperature it has produced, there has been opened up a world of unsuspected powers to man.

A few degrees above that of "thermit" lies the temperature of the oxyacetylene flame formed by the combustion of 1.7 volumes of oxygen and 1 volume of acetylene. The flame thus produced has in its centre a small white cone, at the apex of which the temperature is about 3482° Centigrade. The flame itself consists almost entirely of carbon monoxide which becomes converted at the extremity into carbon dioxide. Surrounding the flame is a relatively cool jacket of hydrogen which, not being able to combine with oxygen at the very high temperature in the immediate neighborhood of the flame, remains temporarily in a free state, and this protects the inner zone from loss of heat, and, in addition, excludes the possibility of oxidizing substances submitted to its action. In order to utilize the advantages of this flame, blow-pipes of special construction have been introduced (Fig. 25), by which with very little practice even an unskilled workman can become proficient in wielding the steady, luminous, intensely hot little flame to its industrial applications. The acetylene employed may be drawn either from one of the ordinary generators or from cylinders containing it dissolved in acetone. The blow-pipe is so constructed that the flame cannot possibly strike back, and it is, therefore, safe.

Let us go one step higher still—a step that carries us, now, within the sunlike radiance of the electric furnace. A vast deal of electrochemical industry depends, either in whole or in part, upon the action of the electrical current *per se*—an action with which, in this chapter, we have nothing to do. We are concerned with the electrical current only as a source of heat; but even with this limitation we are in the presence of an imposing array of researches and industries that illustrates most appositely that saying of M. Berthelot that "*La chimie créé l'objet de ses études.*" For the art and practice of electrometallurgy the world is indebted, fundamentally, to Professor Henri Moissan, of the Sorbonne, for while before and after the beginning of his work other men had done things, his two hundred contributions of new substances and new methods constitute the great mass of electrometallurgical knowledge.

The very idea of using the temperature of the arc-light for a purpose other than that of heating all outdoors began, practically, with Moissan. His furnace of the arc type, the furnace with which he has accomplished nearly all his work, is simplicity itself. It

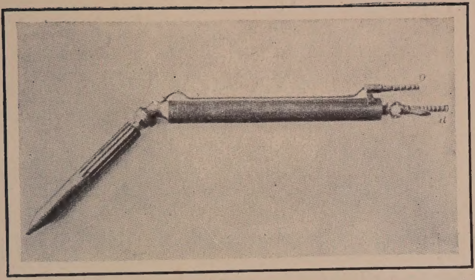


FIG. 25.—THE OXYACETYLENE BLOW-PIPE

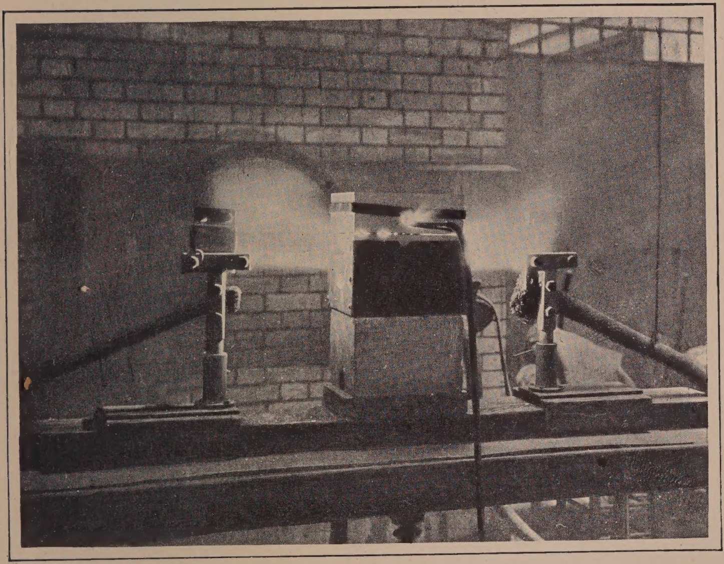


FIG. 26.—MOISSAN'S ELECTRIC FURNACE FOR THE DISTILLATION OF METALS. THE TUBE PASSING TRANSVERSELY INTO THE FURNACE CONTAINS RUNNING WATER, AND UPON IT THE METALS CONDENSE

consists simply of a powerful electric arc between carbon electrodes enclosed in a minimum cavity provided by two blocks of limestone (Fig. 26). The temperature so produced is fully 3500° C., and it is limited to this point only because 3500° is the boiling-point of the carbon electrodes. Out of its blasting, furious heat have arisen many new industries and a new chemistry. In the diadem of factories that encircles the brow of Niagara it may be that the chiefest jewels are these high-temperature industries. There you will find, polished at length into the highest efficiency with the rub of scientific knowledge and sad experience, the Union Carbide Company manufacturing calcium carbide for the production of acetylene. The carbide companies of the world now employ nearly 180,000 horse-power.

Then there is Acheson's factory for the production of that unexcellable of abrasives, carborundum; good for grinding anything from car wheels to pearls, a factory which, it is stated, realizes a profit of $80,000 a year. Near by is Acheson's other factory for the production of artificial graphite, which provides, for a multitude of purposes, graphite which is as good as, nay, better than, the graphite from the mines. Still, again, there is the Readman, Parker, and Robinson process, by which, in the electrical furnace, the phosphorus is stewed out of the mineral phosphates, and passes over to the Diamond Match Company as material to maintain its fires. All these substances have passed through a "burning fiery furnace" before which even Shadrach, Meshach, and Abednego would have quailed in terror—and a furnace, too, which, instead of confounding the golden image of Babylon, ministers to it. With the foregoing processes, cultured laymen are more or less acquainted, but these processes by no means define electrometallurgy.

The fact is, that every new compound discovered is a bundle of unique properties, and the utilities of these properties are there; they await only discovery in their turn. This statement is one of pure faith, held consciously or unconsciously by investigators, but it is the faith that drives the world. Let us illustrate this: carbide of calcium is not the only carbide; thanks to Moissan and his methods nearly every metal has its carbide. For example, there is aluminum carbide, which Moissan prepared some years ago by heating in the electric furnace a mixture of kaolin and carbon. It constituted a body of beautiful yellow crystals which were apparently useless. Now, after all these years, comes the present-day discovery that this Al_4C_3, so produced, on being heated with aluminum (the oxide of aluminum), yields the pure metal and carbonic acid — a wholly new and elegant method of extracting aluminum, and one, obviously, of immense value when developed.

Incidentally, another peculiarity of this aluminum carbide is its slow reaction with water to produce methane or marsh gas. This is interesting to geologists. As everybody knows, in certain parts of America there issue from the earth immense quantities of natural gas which consists almost entirely of methane. Its origin has always been a mystery. We now see that through the abundance of aluminum compounds in the earth, and through the high temperature and pressure to which they must be subjected in its interior, there might easily result the formation of aluminum carbide and its subsequent decomposition by water into natural gas. Furthermore, some carbides yield petroleum on treatment with water, and so we see the possibility, the fair possibility, that carbides were the ultimate ancestors of Standard Oil.

What turns out to be true of this discarded aluminum carbide is potentially true of all the other carbides, silicides, phosphides, borides, nitrides, and other "ides" of this high-temperature research—their utility awaits discovery; they will ultimately be harnessed to industry. But we may signalize discoveries of another character. Thus the organic compound, carbon disulphide, so useful as a solvent and extractive agent, is now most ingeniously and economically made by a continuous process recently devised by which charcoal and sulphur are fed into the top of a stack, at the bottom of which there is an electric furnace which causes their union.

Another recent and very important discovery that it is a real joy to announce, for the benefit of many industries and all laboratories, is a method of cheaply making quartz tubing. This is accomplished by spreading the silica over a carbon resistance rod, and subsequently heating the rod electrically up to the melting-point of the adhering material. By this ready means quartz tubes are obtained which, though they are filled with air-bubbles, and constitute an emulsion of quartz, so to speak, are capable of withstanding intense temperature and variations of temperature, however sudden. The importance of this discovery only laboratory men can adequately appreciate.

Another phase of utility connected with this temperature lies in the extraction of refractory metals which, until the advent of the electric furnace, were practically unknown. It is true that these metals—chromium, tungsten, molybdenum, titanium, and others—may now be made in a purer form by the use of thermit, but by no means so cheaply. Their preparation now constitutes a special and valuable industry in connection with the manufacture of fine steels. Thus, La Neo-Metallurgie, of Paris, manufactures no less than thirty-two most valuable metals and alloys, whose very names were unknown ten years ago—substances such as manganosilicide of aluminum—and others of equally fearsome sound and high industrial interest. Another company, the Société

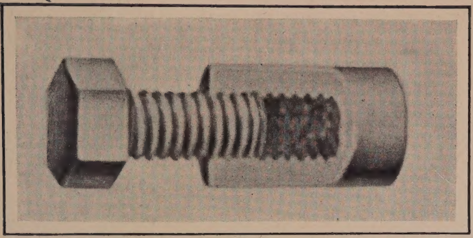


FIG. 27.—CYLINDER FOR THE PREPARATION OF THE DIAMOND

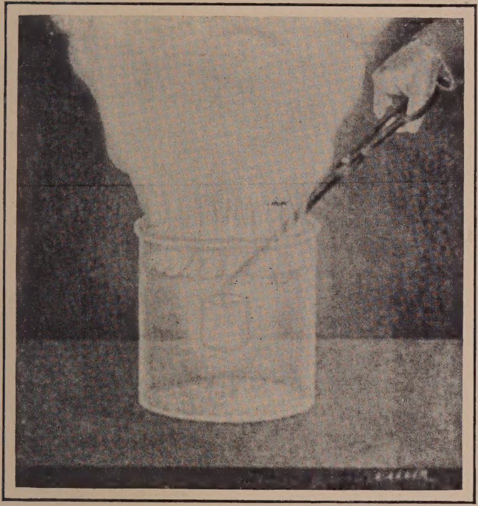


FIG. 28.—PLUNGING THE WHOLE DAZZLING FIERY MASS INTO A VESSEL OF COLD WATER

d'Electrochimie, also of Paris, is devoting most of its energy to the manufacture of ferrosilicium alone. Finally, in this connection, we ought to speak of the synthesis of the diamond.

Molten iron dissolves carbon; so does boiling water dissolve sugar. On cooling, the supersaturated iron deposits its dissolved carbon; so does the cooling water deposit its sugar. The water deposits its sugar in the crystalline condition — as rock-candy — the iron deposits its carbon chiefly as graphite. The object to be attained is to make the iron deposit its carbon in the crystalline form, for crystallized carbon is diamond. To accomplish this, Moissan compressed pure carbon into a little cylinder of pure iron (Fig. 27). This cylinder he then placed in a bath of boiling iron in the electric furnace. Under these conditions the iron body of the cylinder becomes saturated with carbon to the very limit of its capacity. Next, he plunges the whole dazzling fiery mass into a vessel of cold water; at first, "not without a certain feeling of apprehension," says Moissan, and naturally so (Fig. 28). This idea of plunging the molten saturated iron into cold water was a stroke of genius. Molten iron is like water; it expands when it solidifies. On dropping it into water, the sudden cooling solidifies the outer layer of iron, and this holds the inner molten mass in a tight grip; the expansion of the inner liquid on solidifying produces an enormous pressure, and under the stress of this pressure the dissolved carbon separates out in transparent crystalline forms — minutely microscopic forms, it is true—but *absolutely* diamonds.

The largest synthetic diamond yet produced measures less than one millimetre across. In Moissan's laboratory they regard the problem of making larger diamonds as one chiefly of pressure and length of cooking. They deem it quite possible that if they could deal with forty or fifty pounds of iron as they can with four or five ounces their diamonds would be larger. They believe also, and with much reason, that the process of their laboratory is the process of Mother Earth, though down in her secret laboratories she has temperatures and pressures they cannot command and æons of time to perfect her work—the creation of the most beautiful gem that ever delighted man or woman.

Meanwhile the problem may be solved in another way. The curious thing about carbon is that its boiling-point is below its melting-point, so that in order to produce circumstances likely to lead to its adequate crystallization, it is necessary to employ not only a temperature higher than its boiling-point, 3500° C., but high pressure as well—according to the calculations of Sir William Crookes a temperature of about 4200° C., and a pressure of some 255 pounds to the square inch.

The method of obtaining this temperature so high above that of the electric furnace leads us to consider, now, the highest temperature so far reached by man.

According to a paper recently communicated to the Royal Society, Sir Andrew Noble has reached the highest point of temperature in terrestrial thermometry. He has accomplished this by exploding cordite in closed vessels with a resulting pressure of fifty tons to the square inch, and a temperature of no less than 5200° C. Sir William Crookes saw that one incidental result of his experiments should have been the formation of diamond—that is, if his calculations were correct. On working over the residues of the explosion-chamber he has recently extracted from them small crystals that seem to be veritable diamonds. We see, then, that if men cannot control the conditions that make for large diamonds, they, at least, understand them. It is, in all likelihood, a matter of a comparatively short time when the diamond will have been conquered as absolutely as the ruby.

With this final temperature of 5200° C. we have reached the limit of man's present attainment. On looking back, we see that every step in temperature he has so far taken has led him just so far along the path to universal conquest — the absolute conquest which he is destined ultimately to make. But in this phase of temperature alone he still has far to go. We have had evidence from many sources that even in the sun, which is by no means the hottest of the heavenly bodies, and which yet possesses temperatures that transcend anything we know on earth, the very elements of matter lie there disintegrated into simpler forms. Such temperatures are the distant Alpine heights ever and ever so far higher than the slight ascent to which we have so tediously arrived.

VI

MODERN CHEMISTRY AND GLASS-MAKING: THE TYPE OF A CRUDE AND WASTEFUL TRADITIONAL INDUSTRY.

SCATTERED over various parts of the country, but clustered, particularly, along the winding areas of the natural-gas belts, there are operating to-day a multitude of factories sucking up the clean, steady power of the gas by which to store up sand and lime and soda into glass. These factories make yearly 8,000,000 gross of bottles, and a corresponding quantity of window-glass, and of still other glass which translates itself into goblets, and pitchers, and ornaments, and all the great multitude of objects, useful and ornamental, that are utilized by the American people. Consequently, the extent of the industry is fairly expressible by the word enormous; and it is unquestionably worth while to examine into it to find what is contained therein that is interesting and significant.

The first fact that strikes the visitor to a glass factory is that the industry interprets itself in two ways—mechanically, and chemically. Mechanically, it is marvellous. It is creditable, too, in the highest degree, to American ingenuity, for the complicated and efficient mechanisms contained in it are for the most part of American origin and device. There are the huge furnaces, with their lakes of molten glass that are seventy-five feet long, by sixteen feet wide, by five feet deep—furnaces that are started by placing in them a little candle, then a kerosene lamp, and thence by imperceptible degrees up to the glowing heat that they must always maintain while they live. Then there are the mechanisms for pressing the glass, mechanisms that with ceaseless celerity jab the gobs of glass into a multitude of objects, such as cheese-pots and fruit-jars; there are vast "leers," where the red-hot objects travel slowly along to issue into the packing-room at the temperature of the air; there are the travelling stages by which these objects are conveyed; there are the mixing-machines; and, highest development of the mechanical art applied to glass-making, there is a machine which automatically picks up the glass, blows it into the form of a bottle, and drops it into a receiver, and all at the rate of ten a minute.

Along mechanical lines, the American glass manufacturer has nothing to learn from men of foreign speech or race. But glass-making is far from being merely mechanical; however vast it is, it is essentially a problem that is chemical.

The primary materials for glass-making are:

Sand,
Lime, or lead oxide, or baryta,
Sodium carbonate, or potassium carbonate, or sodium sulphate,

and together with these are mixed variably and in variable proportions the oxides of metals, such as manganese, cobalt, copper, iron, zinc, tin, arsenic, etc., as well as other substances, such as borates, phosphates, nitrates, carbon, and other materials.

Even the minutest change in the introduction of some of these chemical substances will make the widest conceivable diversity in the character of the resulting product—and yet in the manipulation of these heterogeneous chemicals there are, we presume, not five real chemists engaged in the manufacture of American glass. The results are significant: It will be shown by facts that have come before the personal attention of the writer, that in spite of the development of mechanical appliances, in spite of the unquestionable expertness of their management, the glassmen conduct their business upon the basis of the motto: "Save at the spigot and waste at the bung"—that the story of American glass manufacture is a story of confusion and waste.

To begin our stories, there is the case of iron in glass. The iron may enter the glass either through the sand, the lime, or the soda. For the most part, it enters through the sand; and more than one-half of one per cent. of iron in the sand renders it unusable for the manufacture of colorless glass. If the iron impurity exists in the ferrous condition it colors the glass green; if in the *ferric,* yellow. Now, the yellow iron is much less detectable than the green, and the consequence is that the introduction of oxidizing agents into the mixture serves to render colorless what would otherwise be a green glass. The oxidizing agents used are either nitre or manganese peroxide. The story applicable to the point is this, that the writer found one large manufacturer using, in accordance with a recipe that he had inherited from prehistoric days, seventy-five dollars' worth of nitre per day in the manufacture of a glass where it had no imaginable function whatever, for the manganese which he already had therein, and for the same purpose, was amply sufficient for the oxidation of the iron in the sand. He was wasting seventy-five dollars a day at "the bung."

Then, again, there is this manganese. If too much of the oxidizing agent is used it colors the glass violet. But the manganese that goes to the glass manufacturer is of wholly variable purity. The consequence is that with every new supply the quantity added must be readjusted; otherwise, violet will result from too much, or green from too little.

On three separate occasions the writer has visited the same glasshouse to see the workmen bailing out a lake of violet spoiled glass from the same immense tank—and all because it was deemed by the foreman "theoretical" to have the manganese analyzed in order that its quantity might be adjusted to its oxidizing value. Thousands of dollars were thus wasted, and thousands more lost through the failure of the firm to fulfil its contracts on time—and all of it would have been saved at the cost of, say, ten dollars for a simple analysis.

A substance used in enormous quantities for American glass is lime. The lime used is, of course, of variable purity. This does not make so much difference to the glass except in the case of one impurity—magnesia. Much of the lime used is made by the burning of *dolomite,* a calcium magnesium carbonate, and in such lime there may be as much as thirty per cent. of magnesia. Such is much of the lime about Toledo, while about Baltimore, on the contrary, the lime is pure. Hence the trouble that resulted to a glasshouse: This company, owing to freight advantages, transferred its orders for lime from Baltimore to Toledo. Immediately there began to appear in the glass white, stony concretions, which rendered the bottles blown from it wholly useless to the trade, and which immediately began to cost the company about a thousand dollars a day: for it must be understood that no matter whether the glass be good or bad, it must be blown into bottles in order to keep the glass-blowers employed; the character of the glass is none of their concern; they are there to "blow."

The foreman of the company did not connect the appearance of the stones in the glass with any change in the lime; but, instead, kept on his course, hoping that the trouble would disappear, and, finally, when it became evident that delay made matters no better, he began adding additional soda—the expensive cure for most of the glass-maker's ills. Still, however, the stones appeared, and so at length, in sheer desperation, he applied to a chemist. The chemist immediately analyzed all the materials used and discovered the apparent source of the trouble in the large amount of magnesia in the lime.

It was his opinion that this magnesia formed an artificial mineral in the glass which crystallized and so constituted the "stones." Unwilling, however, to face the scoffs of the so-called "practical men" of the factory, he determined to prove it, once for all. He therefore submitted a cross-section of one of these stony concretions to polarized light under a powerful microscope, and was consequently able to prove beyond the possibility of question that the stone in the glass was a calcium magnesian mineral, artificially formed in the glass. Having thus found the magnesia in the lime used, and in the stones formed, he went before the company, whereupon there was, of course, a rush for new lime—but not before the company had lost many thousands of dollars which it might easily have saved by the consistent employment of one real chemist.

The utter stupidity and ignorance displayed by glass-makers in the chemistry of their manufacture is vividly displayed in other ways than in the detection of impurities. There is, for example, the making of colored glass. The color of the beautiful ruby glass used for church windows, for signal lamps, and other purposes is due to the introduction either of small quantities of gold, or of cuprous oxide (the sub-oxide of copper), into the glass. A large manufacturer of colored glass for church windows wished to substitute his ruby glass made by gold for that made by copper, for it is cheaper.. He therefore bought from one of the best colormen in the United States ("a practical man") a secret formula for the manufacture of ruby glass due to copper. On endeavoring, however, to realize this formula in his factory the resulting glass came out, persistently, a delicate green, though it should be said that the foreman did succeed in finding in it one day a trace of the ruby color of the area of a pin's head.

After continued fruitless trial, though in the scepticism of ignorance, they applied to a chemist. He obtained from them both the formula and the materials they were using to follow it, and the course of results was as follows: First, he discovered that the "secret" formula which they had bought at a high price was a well-known French recipe for making ruby glass. Next, he found, on examining the materials used, that whereas the receipt called for litharge (PbO) they were using the oxidizing red lead (Pb_3O_4); that while it demanded stannous oxide (SnO), they were using the oxidizing stannic oxide (SnO_2); and, finally, and almost incredible in its folly, that while the recipe, of course, called for cuprous oxide (Cu_2O), they were using the black oxide of copper (CuO).

The singular and childish incompetence of these glass-makers can only be understood by one who knows how dependent the ruby color is upon keeping the copper in the cuprous condition; but even though the reader has but a tyro's knowledge of chemistry, he knows that there may be an enormous difference between "*ous*" and "*ic*," and that one can no more substitute "*ic*" compounds for "*ous*" in glass-making than one can in medicine by substituting, say mercur*ic* chloride (corrosive sublimate) for mercur*ous* chloride (calomel); the results are just as disastrous. Naturally, a readjustment of materials gave the glass-makers their ruby glass.

Reverting to colorless glass, another substance used to a large extent in its manufacture is white arsenic, arsenious oxide (As_2O_3). The use of the substance is traditional, but it may be said with perfect truth that to-day, despite the large amount of money spent on it, it has no known function in the glass. It is a matter of dispute among chemists as to whether any of the arsenious oxide placed in the "batch" remains in the resulting glass; some maintaining that it is entirely vaporized, and others that it is oxidized into the non-volatile "*ic*" condition, and hence remains. But as to what it is *good for,* and why they use it, only echo answers.

The attempts of the glass-makers to improve their own glass are sometimes interesting. One of the magnates of the glass industry thus describes one of his own attempts to improve his glass. "I began," he said, "by taking out the three last things. And what do you think? The glass turned blue!" It is greatly to be feared that the blueness of the glass was due to a trace of cobalt, added surreptitiously by a jealous foreman, for such men do not like office attempts to improve their handiwork.

Much of the cut-glass on the market to-day owes its brilliancy and refractive powers to just such crude and ignorant mixing. It was apparent that the addition of lead oxide to glass increased its brilliancy and refractivity. "Therefore," said such men, "let us add lead oxide to the limit." And so they did, with the result that much of the cut-glass that is sold to-day, even by firms that have made a specialty of its manufacture, however beautiful it may appear at the time of its buying, is, after the lapse of a year or so, clouded, smudged, tarnished, and ruined. The ignorant addition of lead oxide causes the glass, after the lapse of a year or two, to devitrify and to undergo surface decomposition. This is appearing now as a fact of mournful interest to the buyer.

To such an extent is the business of glass-making conducted on a basis of crass ignorance that in accordance with the statement of one of the great manufacturers of soda, "We keep constantly employed a man whose sole business it is to ferret out the troubles of glass-makers." It seems that when things go wrong in the glasshouse it is the usual procedure to blame the soda manufacturer, and he, conducting his business of high scientific efficiency, finds it advisable to employ a man to tell them what their trouble really is.

This ignorance of the scientific conditions governing glass-making is found from top to bottom in the manufacture. It is found in the naïve statement of the head of one company manufacturing lamp chimneys, that he proposed to use crystals of calcite "spar" for making his glass, in order that the property of its transparency might be transmitted to the glass — a mediæval-like statement reminding one of the efforts of the alchemists to make gold by means of sulphur, because of its yellow color.

It is found just as much, however, in the informing talk of the furnaceman, who tells us that: "You may have two furnaces built just the same and in the same place, and yet one will make good glass and the other won't." The fact of the matter is, that in common with the traditional industries, glass-making is conducted on the implication that the art is mysterious, ultra-knowledgable, and extra-scientific, and that when things go wrong the trouble ought to be ascribed, just as it was in the old days, to diabolical influences.

The great financial success of American glass manufacture during the past few years is *despite* its ignorance, and is due to the hungry demands of a growing and prosperous population, to expert office management, to combinations of capital, to the extraordinary advantages in cheap fuel and raw material, and to the protection of a prohibitory tariff. Its actual manufacture is a story of confusion and waste.

It is a fine relief to turn from this chaos of American manufacture to the scientific, orderly practice of the glass manufacture "across the water." Thus, there is at Jena a glass-works which, discarding ignorant prejudice and tradition, began with, and has most successfully continued in, the making of glass with real knowledge. With almost incredible candor, too, they have freely published their results and methods. Under the legend, "Jena glass, and its scientific and industrial applications," the reader, if he looks for it, will find just how marvellously much is actually known concerning the manufacture of this interesting material.

It is to be understood that there is glass *and* glass—that what is good enough for the making of beer-bottles and fruit-jars would be of small utility when applied in optical instruments. Scientific glass originated when men began to understand that future improvement in telescopes, microscopes, spectroscopes, and cameras rested primarily and practically with the glass-maker. Owing to the pressing demands of science, Schott and Abbe, at Jena, entered into a thoroughgoing investigation of glass in an endeavor to correlate all its optical, mechanical, thermal, and chemical properties with the properties of its constituents, in order that by altering the composition of the glass they might know beforehand, and beyond peradventure, its resulting properties.

At the time Abbe and Schott initiated the true science of glass-making there were but five glass-forming oxides whose optical effects were well known; these were silica, potash, soda, lead oxide, and lime. They added to these substances, for the benefit of all coming time, the optical effects of boron, phosphorus, lithium, magnesium, zinc, cadmium, barium, strontium, aluminum, beryllium, iron, manganese, cerium, didymium, erbium, silver, mercury, thallium, bismuth, antimony, arsenic, molybdenum, niobium, tungsten, tin, titanium, uranium, and fluorine. They discovered that by altering the composition of the glass they could alter in a determinable way the hitherto fixed relation between refraction and dispersion; they found, for example, that boric acid is peculiar in lengthening the red end of the spectrum relatively to the blue, and that fluorine, potassium, and sodium had the opposite effect. They found, too, that they could govern the lenses' absorption of light so that, if they wished, they could reduce it to an almost insignificant value for either ultra-violet, infra-red, or visual rays. As a result of the practice of wholly scientific principles of investigation they were ultimately able to duplicate in their optical properties the very best lenses in existence, and yet, at the same time, could do away with the weaknesses and inconveniences to which these lenses were subject in their manufacture and in their use.

The very best glass for the highest optical purposes is peculiarly subject to cloudiness, crystallization, and bubbles. Worse than this, it is also subject to internal stresses which absolutely ruin its efficiency. It is also, in many cases, tarnishable by the air; it is often slightly colored, and, finally, good in other respects, it is often unable to bear the manipulation necessary in grinding and polishing. In discovering, through sane methods of work, means to produce some 2000 new glasses possessed of the finest optical properties, and yet in large measure free from the weaknesses which have generally been considered inherent in glasses possessed of such properties, this firm has in the most material and practical fashion forwarded the progress of astronomy, physics, and biology. It has also placed in the hands of the people, and for wholly practical purposes, instruments of a type of perfection hitherto wholly beyond their reach—instruments such as the beautiful prism field-glasses and the marvellous photographic lenses that are now within the means of every photographer to obtain.

The work of this company has not, however, stopped with the production of glass for optical purposes. It became interested in the mechanical properties of glass as they are related to the properties of its constituents, and in consequence of this, and because of the company's large-hearted generosity in publishing its results, the American manufacturer could to-day, had he even a modicum of chemical knowledge in his employ, produce good, cheap, special glasses for special purposes. Does the user require a glass of a specific hardness for a special purpose? He could have it did the American glass-maker but have the knowledge that is already extant to make it. Does he require for special construction glass of a certain tenacity—or of a certain resistivity to crushing, or of a certain elasticity? Again, he could have it, or he *ought* to be able to have it.

Still, again, there are the thermal properties of glass; these, in a multitude of ways, have an important bearing in the use to which the glass is to be put. The specific heat of a glass may be calculated from the constants of its constituents. The heat-conductivity of a glass may also be calculated in advance with a very fair approximation to its correct value. Then, again, there is the co-efficient of expansion of a glass. The power to calculate this important value in advance, and consequently, to make in advance a glass having a definite expansibility has already resulted in several important applications. It has turned out possible by suitably combining an outer layer of higher expansibility with an inner layer of low expansibility to obtain such a compensation of expansions that the volume remains independent of the temperature. It has turned out possible, also, to weld together two glasses of different but definite expansibilities in such a fashion that the combination is peculiarly tough under the sudden application of heat or cold. From this fact has resulted the manufacture of water-gauge tubes for steam boilers which satisfy in a high degree the requirements of practice. So great is their power to undergo sudden changes of temperature that they may be heated in oil to 230° C., and immediately plunged upright into cold water without flying.

Then, again, there are specially constructed glasses of a high co-efficient of thermal endurance applicable to the manufacture of flasks, beakers, retorts, and evaporating dishes for the chemist as well as of lamp chimneys for the protection of incandescent gas-lights. The lamp chimneys are peculiarly valuable to a people like ourselves, who in such large measure enjoy the privilege of natural gas, and who, even outside of this, are using the gas-mantle ever more and more. So resistive are the chimneys that even in the hottest zone they may be touched with impunity with a stick of ice.

As exemplificatory of the method of work of the scientific men interested in the manufacture of glass in Jena, we shall briefly describe here an investigation into the cause of the color of ruby glass. It will serve admirably as a contrast to that other story of ruby glass which we have presented in the forepart of this chapter.

The introduction of minute quantities of gold into glass produces the ruby color, but the *how* of the process has been for years a subject of bitter controversy. Was the ruby color due to the gold dissolved in the glass as sugar is dissolved in water, or, on the contrary, was it due to minute particles of gold mechanically suspended in the glass? Was it a case of true solution or of colloidal suspension? One or the other it seems to be. The men who solved this question once for all were Siedentopf and Zeigsmondy, and they succeeded

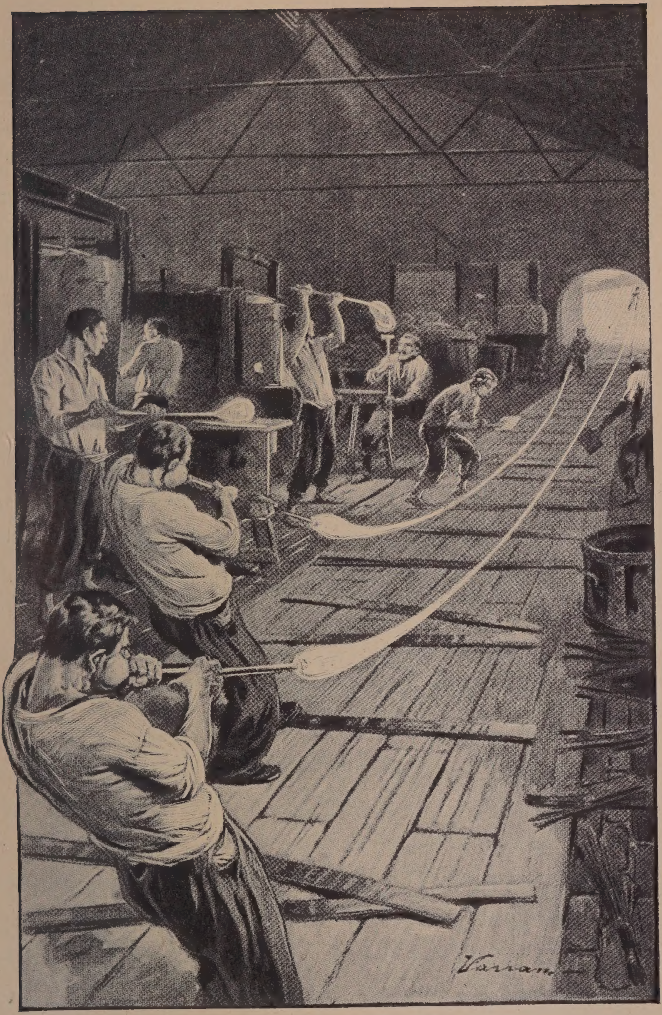


FIG. 30.—BLOWING AND DRAWING THERMOMETER TUBES

by devising and making for this sole purpose a wholly new and beautiful instrument, little known and vastly important—the ultra-microscope.

With this instrument the limits of visibility are enormously extended. In constructing it the discoverers proceeded on the following considerations: The smallest particle which it is possible to see in the best modern microscope is about 1-7000th of a millimetre in diameter, and this value is just about the length of half a wave of visible light. This places a definite quietus upon the microscope in any effort to examine particles smaller still, for it would obviously be impossible for them to reflect the light by which they might be seen; we cannot expect a grain of sand to reflect a wave of ocean—the wave simply embraces the grain. There is, therefore, only one way by which success may be obtained.

One may see particles infinitesimally small if they are caused to emit a light of their own — to become *sufficiently* self-luminous. In order to accomplish this these men passed the light from a powerful arc-lamp through a strong condenser in such a way that it became transformed into a superlatively intense but superlatively minute beam. This tiny wisp of intense light impinges upon the ruby glass under examination, and the small area illuminated by it is examined at right angles by a good microscope. The result is success, for the energy of the intense beam is sufficient to set the particles of gold into vibration so intense that they emit a light of their own by which they may be seen. They were able to see, distinctly and unmistakably, the particles of suspended gold in the ruby glass, and even to measure them, for it may easily be understood that the area of the minute beam may be calculated, the number of gold particles may be counted, and, knowing the specific gravity of the gold and the weight introduced into the glass, all the factors are provided for calculating their average size.

The particles of gold in ruby glass average six millionths of a millimetre in diameter. The smallest particles seen measured 3.9 millionths of a millimetre. The dimensions of these particles lie in the neighborhood of the largest molecules, and, as a matter of fact, it is claimed that, since the discovery of this principle and the making of the instrument, the large molecules of albumen and of certain fluorescent substances have been actually seen. Yet, and this is the astonishing and significant fact in this particular connection, this instrument, with its transcendent and infinitely important powers to science, was devised and made by men interested mainly in one thing—the nature of glass.

If the reader will but reflect upon these contrasting significances he will perceive in them not merely the difference between the domestic and foreign manufacture of glass, but the typical difference between the crude and wasteful methods of the industry carried on along traditional lines, and that same industry prosecuted through the informed spirit of modern science.

VII

INDUSTRIAL ALCOHOL: HOW A SERVANT MAY WORK BETTER FREE THAN BOND

IN Organic Chemistry there is a very large and ever-growing family of substances known as the alcohols; they have all of them certain likenesses that mark them as of one kin, together with definite differences that distinguish them one from another. Each member of this family has its own prænomen — methyl, ethyl, propyl, butyl, amyl, benzyl, and so on. The one bearing the peculiarly graceful name of *ethyl* is the flower of the sisterhood and the subject of this chapter.

We were about to say that ethyl alcohol is a colorless, volatile, fiery liquid, but in beginning to enumerate its properties it became embarrassingly plain that the properties of ethyl alcohol are not in one bundle, but many; that it is the most perplexing substance with which man has ever had to deal; that it is a perfect femininity of varying and conflicting properties. Ethyl alcohol is a powerful agent that functions ubiquitously and contrariously in the affairs of man; it is to be found working in psychology, physiology, physics, chemistry, sociology, economics, and government. Into the consideration of alcohol that is industrial all these functions unfortunately enter.

Consider merely the psychological phase of alcohol: From the time of Noah, the first victim of the grape, men have drunk liquids that contained ethyl alcohol, not because they contained it (they knew of no such substance), but because they contained a *spirit* that could be commingled with the spirit of man; they drank cheer, courage, oblivion, lust, and murder. Only afterwards did it come to be known that all these feelings abided potentially in a certain definite liquid that appeared alike in all the multitudinous drinks of man—in beer, wine, whiskey, gin, brandy, rum, arrack, absinthe, pulke, koumiss, and saké—and that, in point of fact, ethyl alcohol was the people's one drink.

There abides an intoxicating spirit, also, in the other alcohols, but their physiological properties forbid their imbibition. With regard to the physiological properties of ethyl alcohol, there is no settled conviction, as the reader may readily discover by asking his physician and awaiting from him a reply that will almost inevitably be an expression of tradition or of prejudice; but for the other alcohols, there can be no dubiety about it—they are highly deleterious substances. This poisonousness is miserably manifest in the alcohol called methyl.

Methyl alcohol is the chief constituent of "wood spirit," which results as a product of the distillation of wood. Some 10,000,000 gallons of it have, yearly, been floating about America in various use. A not inconsiderable quantity of it is absorbed by the low negro populations of the country, who drink it under the appellation "white horse," or "old mule," or by a pleasing mode of rhetorical transition, and in order, perhaps, to distinguish it from "ethyl," as "Maude." Much of it, again, has appeared in "witch hazel," "bay rum," "eau de cologne," "Florida water," "essences," "Jamaica ginger," "extract of lemon," "liniments," "patent-medicine nostrums," and red ink. Poor and decadent people drink these things, and, barring individual idiosyncrasies, whether it be a man in Indian Territory who drinks red ink, or a man in North Dakota who drinks "Jamaica ginger," there is apparently a fairly uniform result. Out of ten men who drink four ounces each of pure methyl alcohol in any form whatever, four will probably die, two of them becoming blind before death; the remaining six may recover, but of these two will probably be permanently blind. Even the absorption of its vapor through the lungs, or of the liquid through the skin, may produce permanent blindness. The "hearings" before the Committee on Ways and Means afford ample confirmation of this in the procession that filed before it of blind wrecks that had once been hat-stiffeners, varnishers or shellackers, men who did not drink methyl alcohol, but who merely handled it as a solvent; methyl alcohol seems dangerous even in an alcohol lamp. The harm wrought by the substance has been greatly accentuated in the last few years by its manufacture and sale in a purified form, the so-called "deodorized" methyl alcohol, whose smell gives no warning of its deadly nature.

Reverting now to ethyl alcohol, the complexion of the "spirit" of this alcohol, whether it is white or black, an angel or a demon, has been for ages, of course, the theme of poets, and, contrariwise, the rage of publicists. Most men know it to be both, to be an angel-demon. Certainly it has imparted balm and cheer and courage, it has inspired loving-kindness and high deeds, and, it may be, most of the real creative work of the world has been done under its influence; just as certainly, however, has it placed upon the shoulders of man a literal world of trouble, and to it must be ascribed most of the crimes wherewith the face of man is blackened. The real sociological problem, of course, lies not in alcohol, but in the "weaker brother." If alcohol played in fountains and ran in ditches we should ultimately be rid of our problem through the elimination of the "unfit" brother and the evolution of a race to whom it was as nauseous as gasoline. But the brother who is "unfit" in that one respect is generally peculiarly "fit" in certain others, and, anyhow, the very altruism of the race has demanded the elimination, rather, or at any rate, the control of the alcohol.

The governments of the world, looking only at the spirituous properties of alcohol, declared it dangerous and decided, additionally, to take advantage of this sentiment against it; in other words, they have, for a long time, levied everywhere an enormous tax upon alcoholic beverages. This action of government is based, either consciously or unconsciously, upon the curious and significant fact that no increase in the tax, however great, decreases materially the amount of alcoholic beverages consumed; it leads one almost into the belief that alcohol is the normal drink of man; the people *will* drink it. In this country, for example, a "tax" gallon of alcohol, which is about half alcohol and half water, much as it is in whiskey, pays the Department of Internal Revenue one dollar and ten cents; it costs about eleven cents to make. The people of America who drink alcoholic beverages paid as a tax for the privilege during 1904 the sum of $184,893,473.

But the alcohol which thus functions spirituously in beer and wine, whiskey, gin, and rum, may readily be distilled from its crude solutions; and so prepared it constitutes a definite substance with properties wholly in another bundle—chemical properties, solvent powers and heating value, that altogether make it, next to water, the most valuable liquid known; it is, indeed, one of the most important industrial implements of our civilization.

Until January 1, 1907, the United States was the only important manufacturing and commercial country in the world that made no distinction in taxation between alcohol as a beverage and alcohol as an industrial substance. Germany, on the contrary, liberalized her laws sixteen years ago and wholly freed alcohol to industry. The fact that in 1904 the Germans consumed 73,887,610 "tax" gallons of tax-free alcohol, and the Americans not one gallon, is the real reason why in certain industries Germany has grown, head and shoulders above America, the power paramount. On January 1, however, our government actually did give industrial alcohol a limited freedom, and on September 1, owing to an amendment to the law, and unless the Commissioner of Internal Revenue insists upon an unjustifiable surveillance, it will have a practical emancipation.

This commissioner, of course, must positively see to it that no alcohol intended for industrial purposes is used for purposes merely bibulous—as pretty a problem as government has had to solve. For alcohol (ninety-five per cent.) has been selling, let us say, at $2.50 a gallon; out of this the government takes $2.08 as a tax, and the distillers receive forty-two cents; it costs, perhaps, twenty-two cents to make. With the removal of this enormous tax on alcohol for industry, everybody would evade it on alcohol for drinking; for, as everybody knows, alcohol is what every devotee of Bacchus drinks, and it is just as consistent to drink it, if pure, with a suitable dilution of water and the addition of a little sugar, as it is to drink it with all its natural impurities in the form of natural whiskey or wine.

As a matter of fact, perhaps most of the whiskey sold to-day is synthetic "whiskey," made out of straight alcohol and water, with the addition of a little caramel and other deceiving substances — and this, after the payment of the tax of $2.08 on every gallon of the alcohol used for that purpose. It is perfectly plain, therefore, that the Commissioner of Internal Revenue, in order to save his countrymen from dypsomania, his revenues for their government, must in some practical fashion be able to know that the alcohol intended for one purpose is not being used for the other. This is accomplished under the law, and in imitation of the practice of other countries, by the enactment that tax-free alcohol for use in the arts and manufactures shall have first admixed with it certain substances that destroy its character as a beverage. On losing its character as a beverage, it becomes denatured, as they say. Industrial alcohol of to-day is, therefore, denatured alcohol, and it is the nature and utilities and manufacture of denatured alcohol that becomes the theme of this chapter.

The ideal substance for denaturing alcohol has not as yet been found. To understand this one has only to think of the prerequisites. It must be nasty—that is, it must be utterly repugnant—to the taste and intolerable to the stomach, and yet not "sudden death"; it must be cheap, very cheap, else the resulting industrial alcohol will not be cheap; it must be so difficult to remove from the alcohol that it will not pay to attempt it, otherwise, in the sky-scrapers of New York and in the ranches of Kansas, there will be moonshining plants renaturing for beverage purposes the denatured material; its character and quantity must be easy of determination by revenue officers, and, finally, it must not be of a nature such as to interfere with the industrial purposes for which the denatured alcohol is intended.

There is no one substance or mixture of substances that ideally fulfils these conditions, and this despite the prizes, ranging from four to twenty thousand dollars, dangled by the governments of Russia, France, and Germany, and despite, too, the large amount of work done upon the subject by highly competent chemists during the past twenty years. But there are "practical" substances; that is, substances that for practical purposes seem to have answered fairly well within the experiences of European governments. Out of these the Commissioner of Internal Revenue had but to choose.

His first choice was governed by the peculiar exigencies of the situation. The makers of the deleterious methyl alcohol that we have already considered had built up a large usage for their material, owing to the fact that the tax of $2.08 on ethyl alcohol caused the untaxed methyl alcohol to be employed as a substitute at, say, seventy cents a gallon in all those industries for which alcohol as a solvent was absolutely necessary. The freedom from taxation of industrial ethyl alcohol meant, or, at least they said it meant, the destruction of their industry, for no one would use methyl alcohol at seventy cents when he could obtain the incomparably better ethyl alcohol at about half the price.

We now know that this claim was unjustified, owing to the fact that the other products obtained in the distillation of wood—acetate of lime and charcoal—would enable them to continue their manufacture, with methyl alcohol selling at a quarter the price. In order, however, to cause as little damage as possible, and to afford a definite market for the methyl-alcohol industry, it was decreed that the first general denaturant should, in imitation of the French practice, consist of this very methyl alcohol mixed with a little benzine. In other words, that for industrial purposes every 100 gallons of ethyl alcohol (not less than ninety per cent.) must have mixed with it ten gallons of crude methyl alcohol in its most offensive form, together with one-half gallon of benzine.

The result of this first ruling was interesting. The methyl alcohol "trust" immediately sold out to the so-called "whiskey trust," who raised the price of the denaturing material to a height so prohibitive that nobody could make denatured alcohol but themselves. The independent distillers, on complaining to the government, received solace in the permissive ruling of a second general denaturant. This consists, after the German practice, of adding to the 100 gallons of alcohol only two gallons of methyl wood-spirit, together with half a gallon of pyridine bases, the peculiarly offensive constituents of bone-oil. It is safe to say that neither mixture, when mixed with alcohol, constitutes a beverage that any man with a regard for his inner well-being would care to swallow. Doubtless there are certain individuals that will drink it, for men have been known to drink the alcohol from anatomical specimens; but doubtless, too, the government cannot be expected to legislate for degenerates against the needs of the race; indeed, it is probably all the better for the race that denatured alcohol should be allowed to exercise its "eliminating" power in that respect.

The actual danger feared by the government is the possibility of renaturing the denatured product, for it seems of the opinion that the benzine can be washed out and the alcohol rectified to an extent that will permit of its illegal use in beverages. This opinion, beyond all question, does not coincide with the consensus of scientific belief, and it has not been borne out by the experience of other countries. It would be a thousand times unfortunate were the government to destroy, by undue supervision and restriction, and owing to a danger somewhat fanciful, the free use of a product which, as we shall try to show, may carry its manifold and benignant influences to every family in the land.

One of the great industrial uses of alcohol is its solvent power. It is in this respect next to water in importance, and complementary to water in its action. Thus it is used to "cut" shellac, and shellac so dissolved in alcohol literally paints our civilization. It enters intimately into the manufacture and materially into the cost of furniture and of all kinds of wood product, such as passenger-cars, carriages, pianos, billiard-tables, burial-caskets, rattan goods, whips, trunks, shoe-dressing, shoes, fireworks, pipes, umbrellas, and innumerable other articles upon which men use varnish. It is used, again, whenever men employ shellac as a binding material, as, for example, in the manufacture of lead-pencils, in which the shellac, dissolved in alcohol, binds together the moulded graphite; or as in the production of electrical motors and generators, in which the many coils of insulated wire are held in place by this binding shellac; or in the manufacture of stiff hats, silk hats, and straw hats, where the shellac is incorporated in the body of the hat by the aid of alcohol.

In all these industries, the removal of this onerous tax on alcohol has relieved the manufacturer in cost, and the workman of a deadly menace to his health, by eliminating the use of the more expensive, the less efficient, and the very mischievous methyl alcohol from wood. Similarly, it enters as the principal item of cost into the manufacture of the lacquer which is used to enamel the surface of all types of metal objects in order to preserve their lustre — hardware, iron, and brass beds, gas and electrical fixtures, lamps, brass musical instruments, bird-cages, clocks, watches, and toys; all such articles materially benefit in cost of production from tax-free alcohol. Then, again, there are the industries dependent upon cellulose. Celluloid, for example, can be made only through the solvent power of alcohol, or of ether, which is made from alcohol, and so there result material advantages in the manufacture of piano and organ keys, billiard-balls, paper-cutters, combs, doll heads, and a great variety of articles.

Allied to the celluloid industry there is the collodion manufacture, which deeply concerns photography. The people of the United States spend annually about $175,000,000 on finished photographs. Yet into the films from which they are made, and into the papers that form them, this collodion, which is made indirectly and directly from alcohol, largely enters; the tax on alcohol has constituted two-thirds of the cost of collodion. Another industry related to cellulose concerns the manufacture of artificial silk, which is described in Chapter XI. This substance, the subject of a wide manufacture in Europe, has in the past been impossible of establishment in this country, owing to the tax on alcohol, and yet it is estimated that one factory of artificial silk would consume annually about 1,000,000 gallons of alcohol.

Perhaps one of the most annoying effects of the tax on alcohol was its hinderance to the development of the manufacture of explosives. Every pound of smokeless powder requires for its manufacture about 1.4 times its weight of alcohol, and the tax, therefore, upon this powder, due to the alcohol used, amounted to thirty-seven cents a pound. This industry, manufacturing between three and four million pounds of smokeless powder, is thus freed by the removal of the tax from all restraint, and should now be enabled to make its cheapest powder the best; it should, in fact, speedily bring the day when black powder will be as effete as the bow and arrow. One might go on and on with the enumeration of the solvent powers of alcohol, how thus alcohol enters into the manufacture of incandescent mantles, how with tax-free alcohol Americans may now manufacture their own transparent soap which they have been importing to the amount of

14,400,000 cakes from one manufacturer alone, how it permits the establishment of a wholly new industry, such as the alcohol process for the extraction of stearic acid and olea-stearin, but it is already manifest that it is concerned with almost every article of luxury or convenience.

Another wholly different phase of alcohol is its utility as a chemically active body. Its solvent power in the manufacture of smokeless powder is supplemented by its chemical power in the manufacture of fulminate of mercury, the indispensable constituent of blasting-caps, percussion-caps, and cartridges. Almost every pound of this fulminate used in the United States has been made in Canada, owing to the fact that every pound of fulminate produced requires the use of over nine times its weight of alcohol laboring under a tax of $2.08 a gallon. Another utility is found in its chemical function in the production of ethyl ether. This body, wholly invaluable to humanity, may now, thanks to the recent amendment to the Free Alcohol Bill, be made at a price of $2.08 a gallon cheaper than before—the amount of the tax removed.

Another anæsthetic which may be expected at a price much lower than before is chloroform, which, with cheap alcohol, will now, like ether, enter widely, as it has never done before, into manufacturing operations as a most valuable solvent. Again, there is ethyl chloride, which, with "free" alcohol as the raw material of its manufacture, should soon be available to the farmer as a domestic refrigerant superior to the anhydrous ammonia now used, and very much cheaper. To cite still another out of many chemical utilities, there is the function of alcohol in the production of dyes where, as a solvent, or as a medium of interaction, or as a chemically active body, it is invaluable to the industry. The fact that the dyes annually produced in this country are worth only $2,500,000, while Germany *exports* $30,000,000 worth, is significant in part of the difference to industry between the taxed and untaxed alcohol.

Finally, there is the manufacture of fine chemicals into which, of course, alcohol enters. The total value of the fine chemicals produced in this country amounts to less than $5,000,000 a year, while the amount annually exported by Germany exceeds $50,000,000; with "free" alcohol this disparity will undoubtedly be lessened. The whole utility of "free" alcohol as a solvent and as a chemical body may be summed up in the statement that more than 10,000 factories, representing thirty districts, with an aggregate capital exceeding $500,000,000, and employing 300,000 workmen, have been using either taxed alcohol or an inferior substitute; with the removal of the tax these figures will be enormously extended.

One embarrassing situation created by the manifold usefulness of alcohol is the fact that for many manufacturing purposes the general denaturants mentioned above are unsuitable and injurious, and it therefore became necessary for the Commissioner of Internal Revenue to authorize special denaturants for special purposes. Thus, the manufacturers of celluloid are permitted to denature with camphor, the photo-engravers with cadmium iodide, and the manufacturers of embalming fluids with considerably less wood alcohol. An interesting paragraph of the recent amendment permits the use of denatured rum, containing not less than seventy-five per cent. alcohol. This rum is used in the manufacture of nearly all tobacco for the purpose of "cutting" the liquorice which enters into it as, apparently, an essential ingredient, and for the purpose, also, of imparting to the tobacco certain attractive flavors; the commissioner permits its denaturation with nicotine.

But the great fountain of usefulness of industrial alcohol has so far been left unnoticed—its function as a source of light and heat and power. One gram of alcohol, on burning, furnishes 7200 calories of heat, and this fact has interesting and important applications. Thus, while the flame of burning alcohol is practically non-luminous, its heating value makes it, nevertheless, an excellent source of illumination. This is accomplished by permitting the alcohol flame to embrace an incandescent mantle of the type used in gas lighting. In Europe there are hundreds of patents governing the manufacture of alcohol lamps for lighting purposes, and dozens of different types are upon the market. While these lamps differ in the details of their working, in essentials they are practically alike. Fig. 31 is a diagrammatic expression of such a lamp. The alcohol passes up the cotton wick, and there becomes vaporized by the heat of the metal part marked "gas-chamber"; this remains constantly hot while the lamp is burning, owing to the fact that heat is conducted to it by the metal part marked "heat conductor," which lies within the hot mantle and forms a support for it. The vaporized alcohol mixes with air in the "gas-holder," and burns on the top of the gauze within the mantle, which becomes, in consequence, brilliantly incandescent.

In order to light such a lamp, a portion of the alcohol must first be vaporized. In the lamp (Fig. 32) the little knob to the left is the handle of a pump; in order to start the lamp it is necessary first to pump up a few drops, which are ignited by a match. During the time these few drops are burning, about thirty seconds, the chamber becomes hot enough to vaporize the alcohol brought up by the wick, and it is only necessary then to hold a match to the top of the chimney when the alcohol vapor ignites, just as gas does, and immediately heats the gas-mantle to incandescence. The lamp then burns regularly without further attention, so long as any alcohol remains within the bowl.

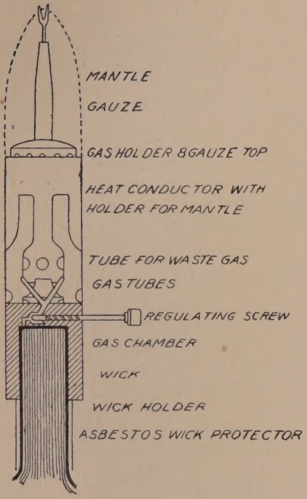


FIG. 31.—DIAGRAMMATIC SECTION OF BURNER OF ALCOHOL LAMP

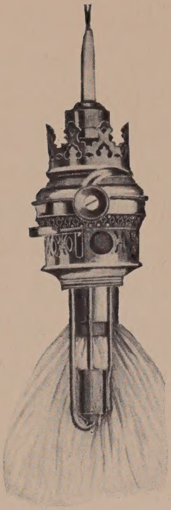
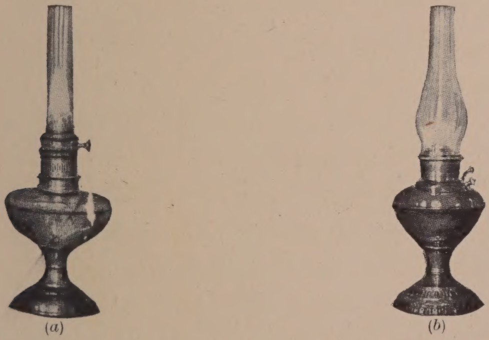


FIG. 32.—BURNER OF ALCOHOL LAMP



(*a*) (*b*)

FIG. 33.—THE TWO LAMPS WHOSE QUALITIES WERE COMPARED

(*a*) Alcohol (*b*) Kerosene

The fact that it takes from thirty to sixty seconds to light is the one annoying feature of the alcohol lamp, and to overcome it the governments of France and Germany have offered prizes of $10,000 to the successful inventor. Its advantages, on the contrary, are many. First, in efficiency. We cite here a report of the Electric Testing Laboratories on the relative efficiency of the alcohol lamp, Fig. 33 (*a*), and the modern kerosene lamp, Fig. 33 (*b*). In the alcohol lamp, one gallon of alcohol lasted fifty-seven hours five minutes, during which time it furnished 30.35 candle-power; with the kerosene lamp, one gallon of oil lasted twenty-eight hours forty minutes, and furnished 30.8 candle-power. The relative efficiency of the alcohol lamp is thus 1732 candle-power hours, as compared with 883 candle-power hours for the kerosene lamp. It thus results that industrial alcohol at forty cents a gallon is able to compete with kerosene at eighteen cents. Professor Rosseau, of the University of Brussels, through a series of careful photometric tests, has obtained results of a similar order.

In other respects the advantages of alcohol for lighting are unquestionable. The light is peculiarly agreeable—it cannot smoke, its odor is quite inoffensive, it is not affected by draughts, it gives but little heat, for the heat of combustion is in large measure converted into light; its wick does not burn; the alcohol, if spilled, evaporates and leaves no spot on the carpet or odor upon the hands, and it is so safe that insurance companies make no objection to its storage. It seems certain that the appearance of alcohol lamps will meet with a grateful acceptance, particularly among the farming communities; all this, of course, on the supposition that industrial alcohol sells at a reasonable price.

But the 7200 calories of heat are good not only for lighting our homes, but for heating them. In Germany and France a multitude of heating mechanisms have been developed and are being used for the application of alcohol as a source of fuel—stoves for cooking (Fig. 34), stoves for heating, and stoves for every human purpose, from heating flat-irons to drying one's hair. The newest stoves are those which, instead of burning the alcohol at the wick, first vaporize it into a "gas-chamber," and burn it in the form of a gas flame. All the advantages inherent in alcohol for lighting naturally belong to alcohol for heating. An interesting form of alcohol now on the German market is the so-called "solid alcohol," or "Smaragdin" (Fig. 35), consisting of alcohol, with a little ether soaked in a harmless form of gun-cotton; it sells for about sixty cents a pound, and requires no special form of stove. Of course, just as with kerosene, the products of combustion of the large alcohol stoves should be carried out of the room through a stovepipe, though it should be said that, weight for weight, the carbonic acid evolved

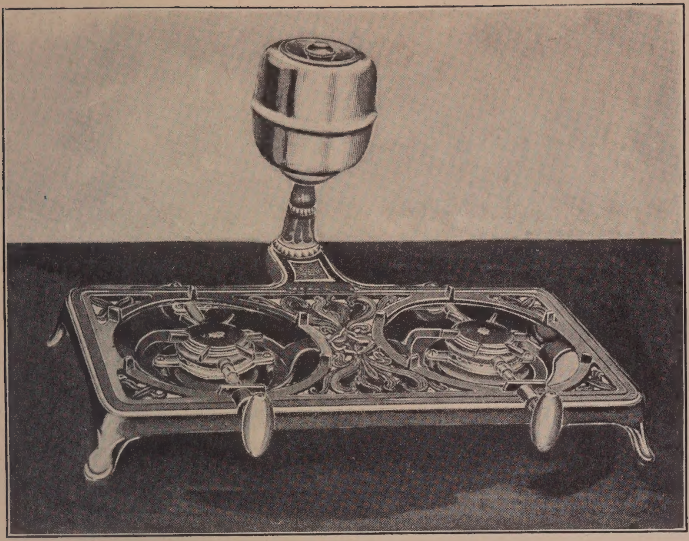


FIG. 34.—TWO-BURNER ALCOHOL STOVE

FIG. 35.—"SMARAGDIN," OR SOLID ALCOHOL

from the burning of alcohol is hardly one-half that from kerosene.

One of the most interesting developments of the past decade has been that of the internal-combustion engine. This type of engine employs a liquid fuel, generally gasoline, which, when vaporized and mixed with air, is compressed and exploded in the clearance-chamber of the engine; the energy derived from the explosion drives the engine. While no gasoline-engine is technically or even "practically" perfect, their conveniences are such that there are to-day in this country over 400,000 in use, and their annual production amounts to 150,000. The question of profitably substituting in these engines alcohol for gasoline is one enormously controversial, but out of the warring testimony there have appeared certain facts that seem unquestionable. Some of these facts relative to the advantages of alcohol as a motive power we shall briefly present.

For the advantages: Alcohol is reproduced in the cycle of the seasons; it is absolutely inexhaustible; it is made out of sunshine and air, and its composition does not lessen the value of the soil or the energy of the earth. Gasoline, on the contrary, represents a part of the stored energy of the earth; it exists only to the extent of about two per cent. in petroleum, and its supply will in the future inevitably fail. To-day, the supply of gasoline is so much less than the demand that it practically cannot be obtained by many who would use it. If all the gasoline-engines in America worked continuously for a day of ten hours they would consume some 4,000,000 gallons of gasoline!

Then, industrial alcohol is practically constant in composition; gasoline, on the contrary, is a mixture, and is badly adulterated; it is not gasoline, but "gasoline." Again, alcohol is beyond all question safer and more cleanly to use. Its safety lies in the fact that it is not so readily inflammable, and that it dissolves in water; in the event of fire, its dilution with water, even to its per cent. in whiskey, will at once extinguish it. Gasoline, on the other hand, is extraordinarily inflammable, and what is much worse, it floats on water; in a gasoline fire the more the water is used the more the fire spreads. This fact for alcohol is of extreme importance in the question of insurance and in its use for motor-boats. Still, again, with alcohol, the smell of the exhaust is almost imperceptible, or, at any rate, by no means unpleasant; gasoline, in this respect, could not endure comparison. Another advantage for alcohol lies in the fact that cylinders and valves do not becomes plugged with residual products as with gasoline, and that its combustion is cleaner and its ignition more perfect. Perhaps the greatest advantage possessed by alcohol in a struggle with gasoline rests in the higher compressibility of its vapor; the compression of alcohol vapor may safely be carried to 200 pounds per square inch, while that of gasoline cannot endure more than eighty pounds without the danger of premature explosion. Next, it requires no more skill to operate an alcohol-engine than a gasoline-engine. Finally, it may be expected that alcohol can always be made in the locality of the demand; it will not require, like gasoline, transportation through extensive distances.

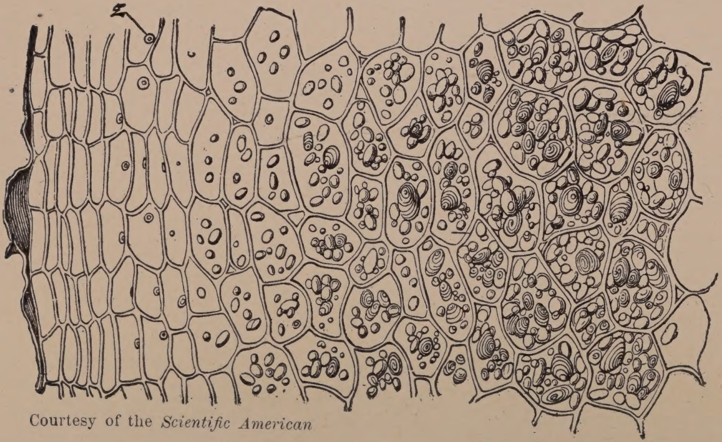
That the foregoing advantages have significance is best seen in this, that while in 1904 there were 3000 alcohol-engines in use in Germany, in 1906 there were 6000; the use has been doubled in two years.

But there are disadvantages also unquestionable. The great positive disadvantage is the disparity in the heating value, for, weight for weight, the heating value of alcohol is only 0.6 that of gasoline; this means, in accordance with practical experimentation recently carried out by Professor Lucke, of Columbia, that other things being equal, a small engine requires 1.8 times as much alcohol as gasoline per horse-power hour. A second disadvantage inheres in its higher vaporizing point, for this necessitates a special modification in the engine in order to secure the complete vaporization of the alcohol and its very best consequent working. The third disadvantage refers to what seems to be a fact that it is singularly easy to burn an excess of alcohol fuel without detecting it, much more so than with gasoline.

As a result of these warring factors, and so far only as to-day is concerned, it seems established that: (1) with proper manipulation any engine working with gasoline or kerosene can operate, unaltered, with alcohol. (2) It can be operated with alcohol only at about twice the cost of gasoline. This is shown in a recent test of fuel economy, in which three automobiles, running on alcohol, a mixture of kerosene and gasoline, and gasoline, respectively, travelled from Trenton, New Jersey, to Atlantic City, 106.8 miles. While the alcohol-engine ran perfectly at a rate of thirty-five miles an hour, it consumed 14½ gallons of alcohol, at 37 cents a gallon, constituting a total cost of $5.36½, as against the performance of its rival, which consumed 7½ gallons of gasoline, at 22 cents, with a total cost of $1.65. The relation of the two is best shown as the cost per ton-mile, which, for alcohol, works out to $0.392, and for gasoline, $0.1354—about half as much.

But there are certain factors, three of them, which, taken together, may, and probably will, before very long, throw the advantages to the side of alcohol. It should be remembered that, with equal cost of running, the advantages of alcohol are unquestionable.

First, the supply of gasoline is rapidly diminishing, while, as we have shown, the demands on it are increasing, and it is easy to see, and reasonable to predict, that its price will continually rise; this despite the fact that the producers of gasoline *could* sell it at a far lower price.



Courtesy of the *Scientific American*

FIG. 36.—CROSS-SECTION OF A POTATO MAGNIFIED, SHOWING THE STARCH GRANULES WITHIN THE CELLS

Second, the disadvantages that alcohol has hardly more than half the heating value of gasoline may be compensated by the advantage that its vapor will endure a vastly greater compression and will yield a corresponding increase in power. The development of engines, in which full advantage is taken of this and other coincident facts, will doubtless materially alter the ratio in the relative economy, and this development the American inventor, now that he has the alcohol to work with, may certainly be trusted to promote. Even now the development has started through a proposal to use, mixed with the alcohol vapor, acetylene from the action of watered alcohol upon carbide, and the outlook for the innovation looks cheerful.

The third factor, however, working with the other two, is the one which ultimately may be expected to make of alcohol a universal source of power; this third factor is the cheapening of the production of alcohol.

The cost of alcohol to the consumer depends upon its cost of production, the restricting influence of governmental supervision and the profit to the manufacturer and the middleman.

Alcohol may be produced from any substance containing starch or sugar (Fig. 36). Consequently, the raw materials of its manufacture lie everywhere, and long-distance carriage is eliminated. Whether it is best profitably produced from sugar-cane, beets, fruits, potatoes, rice, wheat, rye, or Indian corn, depends simply on locality. Whenever the price of a crop sinks below a critical value, either through overproduction or through damage, it may be profitably stored in the form of alcohol. Industrial alcohol will thus steady the price of grain; it will act to the farmer as an insurance policy against loss, for it will provide him with an outlet against a glutted market. While for this reason anything may be turned into alcohol, from bad grain to rotting fruit, the one great present-day source of industrial alcohol, produced to the amount of nearly three billion bushels, and grown in every State in the Union except Nevada, is Indian corn, and it is upon Indian corn that the price of alcohol will, for some time, rest.

Now, one bushel of Indian corn will yield about 2.7 gallons of ninety-five per cent. alcohol, and if we regard the average price of corn as forty cents a bushel, the cost of the raw material is thus fifteen cents for each gallon of alcohol. But to this must be added the cost of production. The production is actually extraordinarily easy. It results through fermentation, due to the action of minute substances known as enzymes, contained in the bodies of certain micro-organisms; it is so easy, in fact, that it is stated that a convict in the Missouri Penitentiary made himself a distilling "worm" out of an old musket-barrel that had been used as a poker, distilled through it the pieces of corn-bread he had saved, and made himself drunk with the tipple. It seems reasonable to suppose, on the basis of recent data, that the cost to the large distilleries, per gallon of ninety-five per cent. alcohol, is about 3.5 cents. One gallon of ninety-five per cent. alcohol thus costs 18.5 cents to produce. But industrial alcohol contains only nine-tenths of a gallon of ethyl alcohol, the other tenth being the denaturing wood alcohol. Allowing, then, 16.65 cents as the cost of the nine-tenths of a gallon of ethyl alcohol, and 4 cents as the cost of the tenth of a gallon of wood alcohol, the cost of industrial alcohol amounts to 20.65 cents a gallon.

The people of the country may, therefore, surely properly expect industrial alcohol at a retail price of thirty cents a gallon, while in certain localities, where the price of corn is low, and where farmers band together for its distillation, it may be expected to enter into active competition with gasoline, pound for pound. The people of Germany have been paying for their alcohol eighteen cents to thirty cents a gallon, a price dependent upon the abundance of the potatoes from which their 6000 farm distilleries make it. In Cuba, where the alcohol is made from base molasses, it sells at a price of ten cents a gallon, and as vast quantities of molasses are dumped on the American shores at three cents a gallon, and as two gallons of molasses will furnish one gallon of alcohol, it appears that notable quantities of alcohol ought to be possible of manufacture on the eastern coast at a cost not exceeding ten cents a gallon. By and large, thirty cents a gallon seems a wholly reasonable present-day price for industrial alcohol. At the same time, much depends on the extent of governmental restriction.

In accordance with the amendment to the law which goes into effect September 1, the manufacture of alcohol is no longer confined to the industrial distilleries, but, just as in Germany, farmers and communities of farmers may freely make it for industrial purposes. This they may do by distilling it into sealed tanks in which the alcohol may be denatured on the spot, or which, with the contents, may be transported, free of tax, to central denaturing establishments. But in the regulation of this the Commissioner of Internal Revenue is given a free hand. If he insists upon an onerous and offensive supervision, if he insists on following the alcohol after it has been denatured—if, in a word, he winds it around and about with red-tape—he will delay indefinitely the progress of its utility. The informed part of the community will watch with interest his action, and will hope that he will find it advisable to *begin,* at least, by letting down bars which he may afterwards replace, as experience shows he must. For otherwise he will increase the cost by lessening the production, and, as well, by throwing the manufacture into the hands of a community of interests.

To-day the retail sale of industrial alcohol is largely, and most regretably, in the hands of druggists, instead, as should be the case, of the hardware dealers and grocers. The sale, on the part of druggists, of industrial alcohol at ninety cents a gallon is a disgrace to commercial decency.

It is obvious, in many different ways, that it will be some time before the manufacture of industrial alcohol is properly delimited, and before, too, the people understand how invaluable a servant it is. But it may be said that just as with Germany and with France so with the United States: there will be with its liberation to arts and manufacture an ever-growing appreciation of its qualities. What has led all governments to an appreciation of this, including, finally, the United States, is not the use of alcohol at its present price of production, but its future price. Men do not look forward to corn and potatoes as the ultimate source of alcohol, but to *cellulose.* There already exist numerous patented processes for the transformation of cellulose into alcohol. Simmonsen, for example, claims that 110 pounds of wood-shavings will yield him six quarts of alcohol, and Classen claims that the same amount of shavings will yield him twelve gallons.

Were these claims true it would mean that sawdust, stubble, straw, chaff, corn-cobs, and old rags would all be veritable mines of alcohol. While such high yields as those mentioned are of altogether doubtful validity in present industrial practice, there is but little doubt that they will be realized in the immediate future. For these processes to succeed, there seems but the need of a little investigation a little more patient, a little more extended. By the time the people of America have learned fully to accept the blessings of industrial alcohol, it would surprise nobody in chemical science were they able to buy it, through its production from cellulose, at from eight to ten cents a gallon. What this would mean towards the satisfaction of human needs the writer, in this chapter, has endeavored in some slight measure to impart.

VIII

FLORAL PERFUMES: THE LAND AND THE LABORATORY

AN inquiry into the objective cause of the sensations that have to do with perfume reveals one of the anomalies of science. There is a transmitting rose and a receiving nose; but concerning the manner of their intercommunication virtually nothing is known. Present-day physics has but a stammering answer to the question: What flies between? The cause of odor, merely whether it is due to wave motions or to particles, is unexplained. Presumably it is, fundamentally, due to particles; but as to the mass of these particles, their velocity, the peculiar motions by which, for example, the emanation of a rose conveys a certain particular idea and the effluvium of garlic one vastly remote, obscurity prevails. Science proceeds by measurement. Light and sound can be accurately measured by photographic and phonographic devices respectively, and there exists in consequence a well-ordered, tenderly trimmed body of knowledge relating to them; but odor can be measured only by the nose, an instrument eminently practical, to be sure, as a detector—so sensitive that it can perceive one-two-thousandth of a milligram of mint in a quart of air—but of small utility as a quantitative measurer of one smell as against another. Some day some fortunate student will devise a mechanism for measuring odors, and with it will open the chapter on the physics of scent.

Concerning perfumes, it seems that they cannot be arranged rhythmically, in spectra, like colors, nor in octaves, like sounds, but that they are unrelated phenomena. Still, one of the curious facts in Odorographia is the masking effect which one odor has over another. It must have been the overweighted consideration of this fact that gave rise to the saying that "the civilization of a country varies directly with the amount of soap it consumes, and inversely with the quantity of its perfumes," a dictum that cannot possibly be sustained. For perfumes are not used merely in lieu of soap and water. Scent is peculiarly a fundamental sense; and about every odor that is distinctively a perfume there are certain phenomena that have to do with the basic feelings of our nature. First, there is the actual agreeableness of a perfume. This is a fact of sensation. A perfumed atmosphere, or object, is likable if (and the *if* is emphatic) the perfume exists as a trace, only as a suggestion; for the appreciation of perfume is most highly developed in refined sensations. Next, permeating a perfumed atmosphere there is another "atmosphere" that the presence of a per-

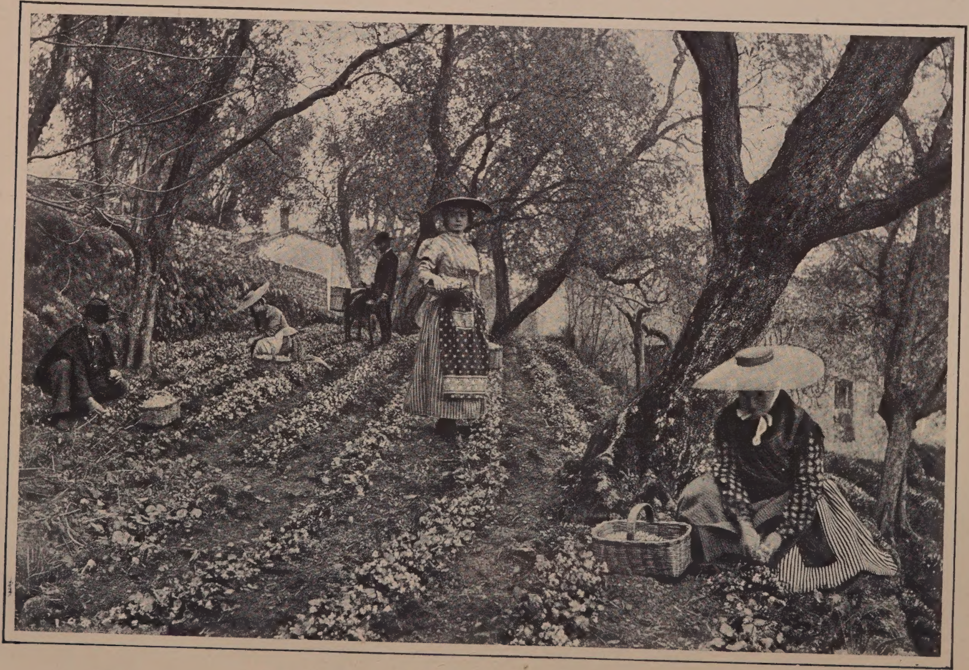


FIG. 37.—GATHERING VIOLETS AT GRASSE

fume inspires. “The sweet south upon a bed of violets” induces not merely pleasant sensations, but softness of feeling—there is an aroma of gentleness; a perfume is an incense. Finally, a perfume has the power, a surpassing power, of lifting up to the surface of consciousness bits of the buried past. This resurrecting power, a sudden perfume and a following memory, is within the experience of everybody.

All these phenomena, physiological, psychological, and æsthetic, are represented concretely as very precious substances that are beautifully vialled and sold: for women love to supplement the color of the petals with these attractive and attracting qualities. In addition, this graciousness that there is about the floweriness of delicately scented objects, and about scented cleanliness, has brought about the use of perfumes in soaps, eau de cologne, aromatic vinegars, toilet-waters, dentifrices, cosmetics, and confectionery to an extent that is as wide-spread as prosperity admits. There is a commerce in them, and it is the nature and extent of this commerce, and something of its relation to American industry, that constitutes the subject-matter of this chapter.

Three industries, with functions wholly distinct, are concerned with odorous materials. The function of the first is to extract from the plant its odoriferous principles in an exceedingly pure and concentrated form. The function of the second has to do with the artificial synthesis of these natural principles or their successful simulation. The third industry, perfumery proper, accepts the products of the other two, and works upon them with its art. The industry for the extraction of the pure, natural essences of flowers has its central seat at Grasse, which, as they used to say long ago, "is the little village near Cannes." It is a quaint, little mediæval town that lies above the Mediterranean in a vale as sheltered as that of Avalon. Here in days of stainless blue, and gold, and below the white of distant Alps, Flora sits enthroned. As in this place she governs the procession of her flowers, so, in accordance with her ruling, act all the merchants of the world that deal in odorous things. Grasse dominates the world in the extracted principles of the perfume flowers.

All the year long the Grassois are a busy people. In March and April come the flowers of the violet and the jonquil—700,000 to 900,000 pounds of violets and about 35,000 pounds of jonquils. In May and June the people are busy with the roses—3,300,000 pounds of them; which, after they have picked, they must overpick, for the petals must all be carefully separated from the injurious pistils. In May and June, too, they are confronted with the task of gathering 4,500,000 pounds of orange-flowers. This is trying work, for the scent from this mass of flowers produces an exasperated and exasperating form of hay-fever; indeed, there is even a peculiar syncope to which orange-flower pickers are subject. In June and July they must gather 45,000 pounds of thyme and 42,000 pounds of rosemary. In July also comes the myrtle. In August and September there are 175,000 pounds of tuberoses, 1,320,000 pounds of jasmine, 65,000 pounds of aspic, and 176,000 pounds of lavender, for which the Grassois send their people into the higher Alps, where they gather it and distil it on the spot. In September and October there is the red geranium, and in October and November the floral year ends with the gathering in of 60,000 pounds of cassie-flowers. December, January, and February are, naturally, fully occupied with the preparatory and anticipatory work of the coming season.

The total weight of the flowers gathered annually in the neighborhood of Grasse must approximate ten to twelve billion pounds. The number of flowers this weight represents is almost incredible. Consider one kind of flower only: The average weight of a jasmine-flower is about 120 milligrams, and consequently the season's gathering of jasmine alone represents the formidable figure of five billion jasmine flowers picked by hand. It may be remarked that two-thirds of the people of Grasse live to the age of seventy.

The people of the distilleries are as busy as the flower-pickers, and when the flowers are resting they extract the essential oils of exotic plants—the ylang-ylang of the Philippines, the female rosewood of Guinea, the oils of cinnamon, of cloves, of sandalwood, of patchouli, and many others.

The methods by which the Grassois extract from the flowers their subtle and delicate perfumes show them to be well aware of the rivalrous times in which they live; they are unresting in their efforts to realize the highest ideals of their art.

Rosemary, thyme, lavender, geranium, roses, and orange-flowers they distil with steam in alembics that range in containing-power from 300 to 60,000 quarts. The steam and extracted oil subsequently reassume the liquid form in suitable condensers, whence the oil is readily drawn off. The water-distillate from the flowers is conserved in huge receivers, for it is, of course, saturated with the valuable essence; it is either used over and over again in the alembics, or, in the extraction of certain flowers, it is sold as "distilled waters." There is rose-water, there is jasmine-water, and there is orange-flower water literally sufficient to float a frigate. All told, about 4,000,000 quarts of "distilled waters" are salable at Grasse at the rate of five cents a pound.

For the extraction of delicate and fugitive flowers, such as the jasmine, the tuberose, and the jonquil, the method *par excellence* is that of cold *enfleurage*, by which the flowers are placed upon the purest of pure

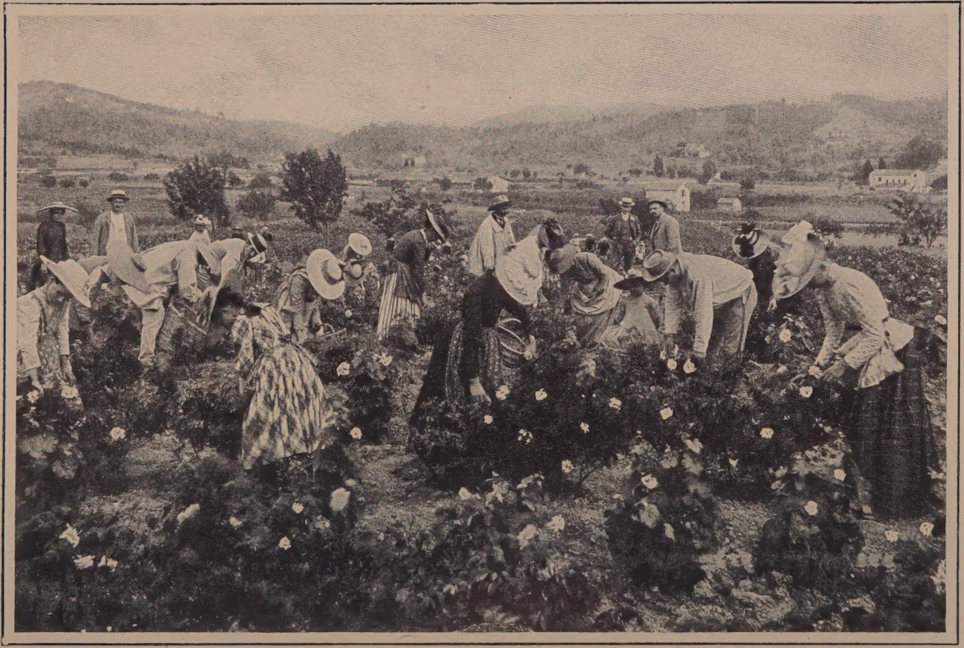


FIG. 38.—CUTTING THE ROSES AT GRASSE

cold lard held upon glass plates in wooden frames. Every day fresh flowers are laid upon the lard, until it becomes a saturated "pomade" of essence. This solution of perfume in lard is then extracted with cold alcohol continuously paddled into agitation; the alcohol is then evaporated and the concentrated extract is obtained as the "quintessence" of the flowers. A somewhat similar method is that of *hot maceration,* in accordance with which the flowers are immersed in, and continually paddled in, lard that is melted and hot. The perfumed lard is afterwards separated from the exhausted flowers by filtration and pressure (Fig. 41). In this way is obtained the "quintessence" of roses, orange-flowers, cassie, and violets. Finally, there is the process, entirely modern, employing volatile solvents, by which, in a closed extraction apparatus, light petroleum spirit dissolves the essences, and after evaporation in a vacuum leaves them in a solid form as the *parfums solides*—a process good for all flowers alike.

The essence extracted from any one flower depends, in its quality and in its quantity, upon the method employed. Thus, a pound of oil extracted from orange-flowers through distillation by steam is worth $36, through petroleum-ether $72, and through melted lard $136. Essence of violets extracted by petroleum is worth $163 a pound, while extracted through lard the price of a pound rises to $1363. With most flowers, though, the quantity of perfume extractable is greater through lard than through any other process. This has given rise to the theory that the flower, even after decapitation and immersion in the lard, is a veritable little factory that lives and continues to produce its perfume. It is a pretty theory, but it cannot be held in the light of recent knowledge. Just as soon as the blossom is separated from the twig that nourished it, it is dead. Of the perfume which the blossom holds, only a small part of it exists in a free state, the remainder being held in inodorous combination with the glucosides. The explanation of the fact observed lies in this, that under the catalytic action of certain enzymes existing in the flower this bound perfume is gradually set free even after the death of the flower. This explanation has a learned sound, but the Grassois are an earnest people, and such things interest them. They are not resting content with the purity and volume of their products, even though these command the respect and admiration of the world, nor with the $6,000,000 which are the yearly fruits of their toil. They strive in every way to make their process *rational.* Thus, to-day, they are inquiring into the parts of the plant in which exist the essences, and the propitious epoch for cutting the flowers; they are investigating the influence of external causes on the growth of their flowers, such as the temperature, the degree of humidity, the electric tension, the light, the nature of the soil, and the catalytic action of enzymes.

Outside the progressive character of the race, the reason for this absorbed care is not far to seek. There is a foe in the field, impersonal but deadly, and they are sane enough to arm themselves. They have to meet the onset of chemistry and the second industry concerned with odorous materials. To illustrate this fact: The chemist has investigated the essence of jasmine, and he has discovered that it possesses the following percentage composition:

JASMINE

Benzyl alcohol	6.0
Linalol	15.5
Jasmone	3.0
Benzyl acetate	65.0
Lenalyle acetate	7.5
Methyl anthranilate	0.5
Indol	2.5
	100.0

He has discovered, apparently, every constituent in oil of jasmine, and as a consequence he has only to make and mix these constituents in his laboratory to provide the pure essence. And so this extract from the trade-circular of a great firm of manufacturing chemists tells it own story:

JASMIN SPÉCIALITÉ

Essence de jasmin artificielle	
en flac. de 10, 20, 50 et 100 gr.	.420
250, 500 gr. et 1 k°.	.380

It behooves us now to discover whether this struggle between the land and the laboratory, between the natural and the artificial, must inevitably be a battle *l'outrance,* desperate and merciless; or whether, with science the ally of each, there may ultimately result a friendly co-operation to the help and profit of both. Will what happened to the alizarin and indigo dyes happen to the essential oils? Let us see what the laboratory has accomplished. The laboratory rival of any natural substances may be a chemical, artificial product which is absolutely identical with it both physically and chemically. Twenty years ago the triumphs of the present day were anticipated in the discovery that the essential constituent of oil of bitter almonds was the substance *benzaldehyde,* capable of laboratory production from coal-tar. To-day it is being manufactured on an extensive scale for the requirements of the dye-stuff industry. Its price is but one-tenth that of the natural product. Until recently it was impossible to use in perfumery because it contained traces of impurities that ruined its aroma. Now, however, under the legend "benzaldehyde free from chlorine" it is pure, and available to the perfume industry.

Another essence which has yielded up its secret to the chemist is oil of wintergreen, which turns out to be essentially *methyl salicylate,* and this methyl salicylate, prepared by processes with which the plant has

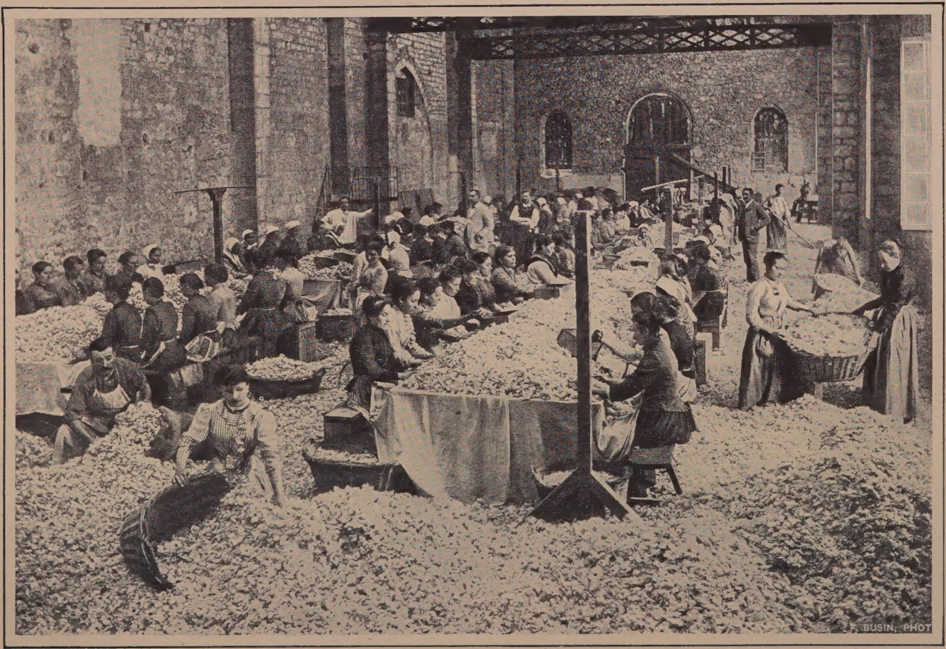


FIG. 39.—SEPARATING THE PETALS FROM THE PISTILS OF ROSES

nothing to do, is a product of large sale, and is as "official" in the United States Pharmacopœia as the natural oil. In the leaves of the "deer-tongue"—an herb that grows in abundance in Virginia, Florida, and Carolina—there exists an essence called *coumarin,* of delicate and tenacious odor—the basis of the perfume known as "new-mown hay." This coumarin has been successfully synthesized, and its German manufacture compares in a healthy way with the American plant. The most important of the absolute syntheses of the natural oils is *vanillin,* which is the predominant odorous principle of the vanilla-pod—the fruit of a species of orchid growing wild in Mexico and thereabouts. The extracted essence of this "pod" is vanilla, the subject of a wide usage and a large commerce. Now, the basic principle of this essence is methyl-proto-catechuic aldehyde, called, for short, *vanillin.* This vanillin occurs not only in the vanilla-pod, but in benzine, assafœtida, beet-sugar, asparagus, pine resin, Peru balsam, and to some extent also in the husk of oats, in cork, in the bark of the lime-tree, in potato-peel, and a dozen other places. This illustrates how wide-spread may be the occurrence of a natural oil. It was first prepared artificially by Tiemann from *coniferin,* which occurs in the cambium layer of various woods. Later came its production by the oxidation of eugenol, the chief constituent of oil of cloves, and this is to-day the starting-point of dozens of patents governing its manufacture. There are still other starting-points which, while they were interesting when vanillin was worth fifty-five dollars a pound, are at this time only academically so when the price is but one-seventh as great. The total production of artificial vanillin fluctuates about 25,000 pounds a year.

An interesting process is that of a company of American manufacturers. Out of cloves from Zanzibar they obtain oil of cloves; out of the oil of cloves they extract eugenol; this eugenol they transform into iso-eugenol, which, through the action of ozone (almost the only successful application of ozone in industrial chemistry), passes directly into vanillin and acetate acid.

One of the great recent triumphs of organic chemistry is the synthesis of veritable camphor, though it is of no commercial moment; and still another is the artificial production of natural *nicotine*.

But manufacturing chemistry is not limited in its competing power to the production of the actual natural substance; it may throw into the market a body wholly different in chemical composition but possessed of similar specific properties. The laboratory may successfully simulate the product of the land. Thus there is *artificial musk*, which has no known chemical relation to the secretion of the musk-deer. It is made most successfully and on a large scale by several methods; the commercial product is generally tri-nitrobutyl-xylene mixed with nine times its weight of acetanilide.

Other imitation products are mono-nitro-benzene and mono-nitro-toluene, which, under the name of "oil of mirbane," substitute the natural oil of bitter almonds for the purpose of scenting soap. Still others are amyl acetate as essence of jargonelle pear, amyl valerate as essence of apple, cinnamic aldehyde as oil of cinnamon; and, of course, there are others.

Still, again, manufacturing chemistry will sometimes produce a substance that is neither a natural product nor the imitation of one, but, instead, has properties that are wholly new and very valuable to the industry concerned. Thus, *heliotropin* is a synthetic product that gives to the perfumer a new note in the scale of available odors. It has a peculiarly sweet, persistent odor, and mixed with vanillin it constitutes the perfume known as "white heliotrope." Made originally from piperine extracted from pepper, it is now prepared commercially by the oxidation of safrol, which occurs in the essential oil of sassafras and in oil of camphor. When first introduced it sold for $336 a pound; now, under improved methods and through competition, the price is less than $3 a pound.

Another chemical product that has proved acceptable to the perfumer is manufactured from oil of turpentine, which, when the chemist has run it through a course of reactions, ends as *terpineol,* with the pleasant, sweet odor of lilac. It serves for the preparation of the scents known as "white lilac," and is peculiarly useful to the soap-manufacturer, for it is resistant to the action of alkalies. The eagerly desired perfume of the violet finds its synthetic rival in *ionone,* which, after years of patient labor, has been successfully manufactured from oil of lemon and from lemon-grass. It, or rather they (for there are two ionones closely related), are now the subject of a considerable manufacture, many patents, and an embarrassing lawsuit. Having in a state of extreme dilution the characteristic odor of "fresh" violets, they have been received with vast enthusiasm. In addition to all the artificial essences mentioned above, there are also iso-eugenol, used in the preparation of artificial "carnations"; benzyl alcohol, with the odor of hyacinth; anisic aldehyde, or liquid "hawthorn," and the ethers of beta-naphtol, with their odors of acacia and orange-flowers; finally, there are indol, methyl anthranilate, and phenyl-ethyl-alcohol, which enter into the synthetical rose, jasmine, ylang-ylang, and neroli scents that are offered on various sides.

It must be obvious, on the basis of this fair catalogue of the achievements of synthetic chemistry, that their effect could not be inconsiderable; but it is a matter almost of astonishment to find the nature of it. For example, neither the consumption nor the price of natural musk has decreased since the inflow of the

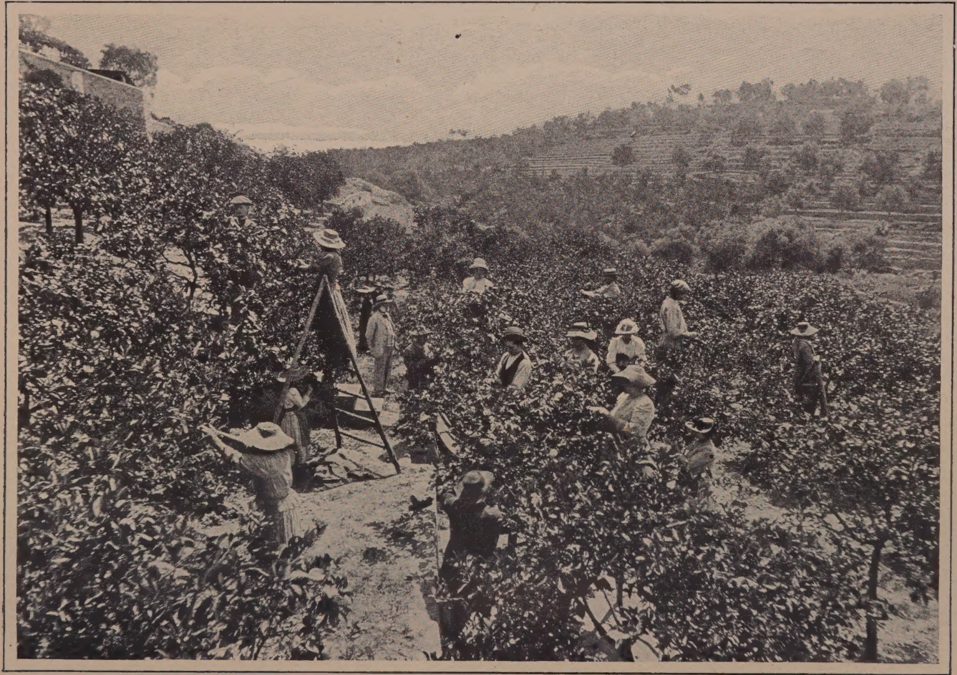


FIG. 40.—THE ORANGE-FLOWERS AT GRASSE

artificial musk of Baur. Since the coming of commercial synthetic vanillin, the vanilla has always been cultivated, its importation has not diminished, and its prices have consistently been maintained. The only effect of the advent of ionone has been an enormous extension in the cultivation of the violet.

In no one case has the coming of a synthetic perfume injured the market of the natural product. The reasons for this are plain and significant. The manufacturers of the natural oils have earnestly enlisted the aid of science. The parent substances for the preparation of the synthetic oils are for the most part plant substances—not coal-tar; the business of synthetic oils is tributary to the vegetable kingdom. It is impossible to manufacture perfumery of the highest grade out of synthetic preparations alone, for the natural essence generally contains minute traces of other substances that have their value. Thanks to the chemical products, the perfumer, the confectioner, and the soap-manufacturer have been enabled to produce articles at a low price that have found a new clientèle—the poor. Thanks to chemistry, there has been a rapid progress of the lower classes towards a comfort and a luxury hitherto reserved for the privileged rich.

These two industries, the natural and the artificial, afford the raw material for the third — perfumery proper. This industry is not a science but an art, in which success depends upon the exercise of a creative imagination carefully tempered with good taste—qualities which Frenchmen have always been admitted to possess, and which explain Paris as the centre of perfume confections. The great perfumer is a musician in odors. With some eight notes in his scale, such as the orange-blossom, rose, violet, jonquil, mignonette, jasmine, tuberose, and cassia, and with a multitude of grace-notes from scented woods, herbs, and flowers, he strikes a harmonious chord of scent. A "scent" never consists solely of the essence of one flower. It must have persistency or staying power; it must have intensity, and it must be superlatively agreeable. These qualities are obtained only by the most artful combination; every "scent" that is exquisite is a "creation." The perfume of the violet has in one instance the following composition: essence of violet, natural vanilla, tincture of orris-root, a touch of vetiver, essence of the leaves of the violet, and artificial ionone. The "lily-of-the-valley" scent consists of the essences of the jonquil, the tuberose, and Oriental oil of rosewood.

For the perfumer to make his successes, his essential notes must be *pure*. Anosmic people, or even laymen with the sense untrained, can hardly appreciate the enormous difference that lies between a pure and an impure odorant body. There is all the difference, and the offence, that there is to the musician with one note slightly, even very slightly, out of tune. But to the perfumer the impurity has not only the offence of the jarring note; it actually suppresses or alters the others. A pure essence is like a plate of transparent glass—the faintest smudge ruins its quality. Thus, indol — a substance with an odor absolutely loathsome—appears, when carefully purified, with a powerful, agreeable aroma; and not only so, but it turns out to be an integral part of the delicate perfumes of the jasmine and the orange-blossom. Scatol, as abominable in its odor as in its name, is also most agreeable when pure, and it exists as a constituent element in the perfume of civet. Raw vanillin smells but little; it is only when purified that it exhales its powerful familiar odor. The absolute necessity of purity, therefore, makes it all the more regrettable that Science is employed to degrade her own products with adulterations. The amount of adulteration of essential oils intended for consumption in America constitutes a scandal; most of it is perpetrated abroad and with the most careful application of science. Fortunately, Science knows her own methods, and by determining the physical constants of the oil, its congealing-point, its specific weight, its rotary power, its viscocity, and its solubility in alcohol, the user may have what he is entitled to—what he *thinks* he buys.

Finally, as the result of all this careful, even loving, work from petal to perfume, there arises a delicate, sweet, intense, and very precious composition casketed, with all the embellishments and refinements of modern art, in bottle, label, box, and wrapper; and so it proceeds to the uttermost countries of the world, bringing with it something of the grace of Paris.

This little study in perfumes shows that the Grassois, like the ants, "are a people not strong, yet they prepare their meat in the summer," and that this they do despite the world of lands and people that lie about them, and despite, too, the aggressive science of the present day. In doing this they afford a lesson not only to all provinces, but to the whole world, that the summerland is not of necessity a land of languorous ineptitude.

Compare the products of these ten billion pounds of flowers grown along this little countryside with the products of American extraction. The diversity of climate in the United States, the emulative character of its citizens, and its aggressive tariff should all conduce to the manufacture of plant essences in a fashion to command the respect of the world. And yet the only plant essence of any real importance extracted in the United States is oil of peppermint — about 150,000 pounds of it, hardly half that of Japan. Possibly we ought to mention small quantities of oil of wormwood, oil of wintergreen, spruce oil, and witch-hazel, but they can hardly be considered seriously in the trade of essential oils.

Everybody knows that there exist in this country,

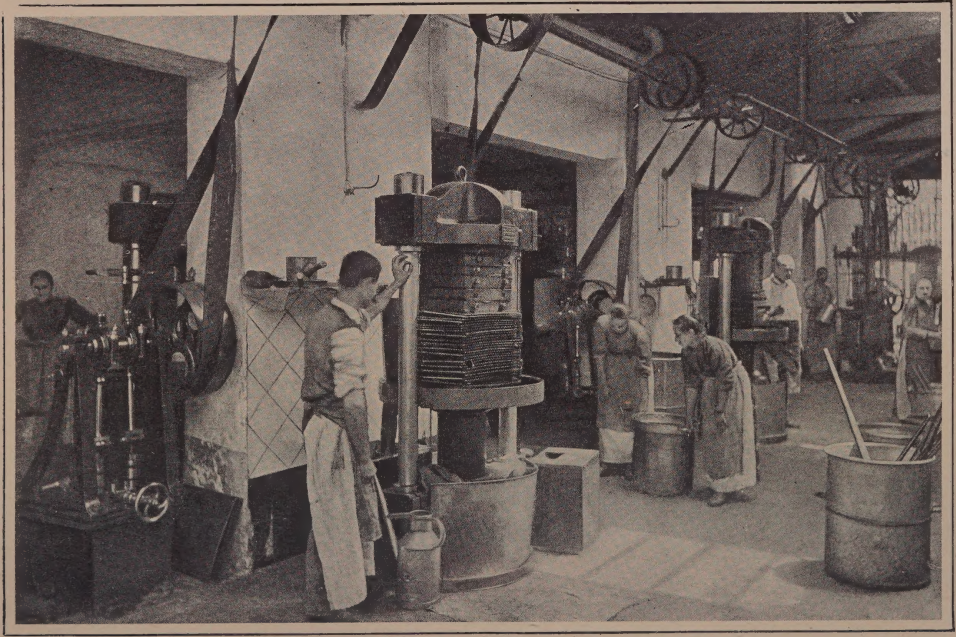


FIG. 41.—PRESSING THE LARD FROM THE EXHAUSTED FLOWERS

both East and West, nooks as privileged in climate as the Riviera, as benignant to the growth of flowers, and consequently one looks with curious interest for the production of the queen extracts of rose, violet, orange-flower, jonquil, lavender, etc.—in other words, for a rivalry with the products of the people of Grasse. One looks naturally in the admirable Census Report of the United States, and one finds—*nothing*. Whatever the cause, this much is so: that the total production of essential oils in America does not exceed $500,000—about one-twelfth that of a little town in France.

For much scientific information concerning the essential oils of perfume I am indebted to M. Paul Jeancard, of Cannes; and for an introduction into the practical working of the manufacture, to the *Parfumerie de Notre Dame des Fleurs* of M. Bruno-Court at Grasse.

IX

THE MAKING OF MEDICINES: HOW SCIENCE MAY SUPPLANT EMPIRICISM

THE one hundred and thirty thousand physicians in America do not make the medicines with which they dose their patients: they prescribe. The thirty-five thousand pharmacists who fill the million and more prescriptions with which they are confronted every day do not make these medicines, either: they dispense. These medicines are all either made or gathered by industrial organizations known as "manufacturers of pharmaceutical preparations"; every ounce of medicine swallowed by every patient in America comes, practically, from some such shop. Now, the physician must undergo a most arduous training before he is permitted to prescribe; the druggist must undergo a training almost equally arduous before he may dispense; but the manufacturer of the substances which the physician prescribes and the druggist dispenses needs only "hang out his sign"; no professional training or educational qualification is deemed legally necessary for the manufacture of drugs.

The ancient Sieur de Montaigne used to prefer his medicines so manufactured without either the authority of the law or the schools. For, said he: "There is no poore Woman so simple, whose mumbling and muttering, whose slibber-slabbers and drenches we doe not employ. And as for me, . . . I would rather spend my money in this kind of Physicke than in any other: because therein is no danger or hurt to be feared." But this was in the days long gone, when the remedial agents of the people consisted of a few simples from the herbs of the field, and when experimental medicine was carried on by physicians like Paracelsus, who stood by the bedside of his patient, watch in hand. "Kill or cure," said he, "in five minutes."

Now all things are changed. Man has heedfully viewed about him the infinite number of things (creatures, plants, and metals), and out of them he is compounding or extracting a bewildering number of substances of alleged thereapeutic value. In one list of the newer remedies arranged under their trade names there are presented under the single letter A, from Abrastol to Azurin, no less than 418 separate titles. The determination of the full physiological properties of these numberless substances is so difficult and so limited in its possibilities, their methods of preparation are for the most part necessarily so elaborate, and they are often so deadly through any mischance of preparation, that it is a nervous business, even the bare thought that it is *possible* that the manufacture of such things may be in the hands of people employing ignorant or inadequate methods, or who are actuated solely by the hope of gain. But in addition to the new remedies there is a vast number of old ones that have been gathered up through the experiment and experience of our ancestors. These, most of them, have a value more or less definite and unquestionable, and more or less understood. But it is a matter of fact that less than fifty per cent. of the "standard" preparations that appear in the Pharmacopœia have been standardized, and it is true that in the manufacture of the 10,000 drugs and combinations of drugs that are being used by the physicians of the country there is more opportunity for fraud through adulteration and substitution than in any other manufacturing industry known among men.

So, because any man however ignorant, with any motive however ignoble, may manufacture and sell any of the 50,000 compounds known to organic chemistry and may allege for them what curative powers he will, and because, too, of this unlimited opportunity for fraud among the older drugs, it becomes a matter of no surprise to learn that at the present time among the great number of firms manufacturing remedial agencies there is the greatest conceivable diversity in science, sincerity, and wisdom. Owing, however, to the recent passage of an act known as "The Pure Food and Drug Law," this diversity of character has not its sometime interest. The scientific people who are charged with the fulfilment of this law certainly mean science, sincerity, and wisdom, and mean it all intensely, and it may be taken as a fact that slowly and with much fumbling, but implacably, because of them, there will be garroted both Messrs. Quack and Cure-all, who yearly sell their hundred million dollars' worth of nostrums to the people, as well as Messrs. Cheap and Deadly, who sell their adulterations and substitutions to the physicians.

What is interesting, and in a present-day and very literal sense vitally interesting, is the extent to which scientific method may possibly be applied in the making of these substances; for to writer and reader alike there will come a time, and lucky shall he be if it comes but once, when from a vial or through a needle he will take in them the issue between life and death. Whether it be hypnotic, stimulant, antipyretic, antiseptic, antitoxin, or what not, if it be insincerely or ignorantly or carelessly made, the earth may cover a mistake but for which he might be walking among men in the sunlight. Because of the vital interest related to this manufacture, and because it illustrates beautifully what men may succeed in doing, when they have the will, in employing scientific method in a business where it would seem impossible of application, and because, finally, it affords an object-lesson of the fact that the intelligent application of scientific method pays, always and wholly, the subject of modern science and drug-making constitutes the substance of this chapter.

The subject is best exposed in a few facts that are significant and illuminating, and this may be done by observing a little of the practice of one firm that is typical of the best. This firm may be hight Messrs. Method and Efficiency. It avails but little to lose one's self in their warrens of offices, or to penetrate the buildings where those marvellous machine-automatons are turning out the millions of pills and tablets, or even into others where the medicinal agents are being manufactured, magnificently, in gross. To the briefest glance of knowledge it is apparent that this business, from top to bottom, as much as may be, is governed throughout by Method and Efficiency. The matter that is really interesting and signficant is not how they do things here, but how they *get at* things, what they find it humanly possible to do to insure the virtue of those little potencies that in the form of pill or tablet or powder or elixir are on the way to all of us, rich and poor alike. Into the laboratories, then, it is necessary to go, for it is there that the method and efficiency of the firm begin and end. To illustrate this there is the preparation of the old and standard drugs.

These drugs come from the uttermost parts of the earth—from the dank forests of Brazil, from the frozen Siberian steppes, from the banks of the "gray-green, greasy Limpopo River, all set about with fever-trees," or from "silken Samarkand"; but almost everywhere they are gathered by barbarous peoples, the lowest of earth's denizens. It is small wonder, then, that with any one plant there should be a variation among its individual specimens in the proportion of the active medicinal agent it contains. But when we add to this the fact that, in general terms, the per cent. of the active ingredient depends on the amount of sunshine it enjoys, on the time of the year it is gathered, even on the time of the day, on the amount of moisture, the elevation, the character of the soil, and a dozen other factors, it becomes almost a necessity of thought that the amount of "medicine" in that plant must vary from a maximum to nothing at all.

Such crude drugs are now assayed for their per cent. of medicinal activity, and, in this firm, by a Testing Department consisting of a large corps of able chemists and pharmacologists provided with an equipment that would do credit to any university.

First there is the chemical assay. To take an example: There is the herb hyoscyamus, or henbane, a clammy, fetid, narcotic annual or biennial. In the old days it was used to cure the gout, in accordance with this running invocation delivered to it the night before: "Sacred herb, I bid thee, I bid thee, to-morrow I summon thee to the house of my patient to stop the rheum of his feet. . . ." The next morning, before sunrise, the herb was dug up with the bone of a dead animal, sprinkled with salt and conjurations, and hung about the gouty patient's neck. Nowadays, the crude drug is extracted in enormous quantity with alcohol, and a test sample of the "fluid extract" is then analyzed by setting free its active therapeutic alkaloids with ammonia, dissolving them out with chloroform, and ultimately titrating them with sulphuric acid. In this way the company positively knows the therapeutic activity of the extract which it has manufactured, and it is also able, through two subsequent analyses, to dilute or concentrate it to a liquid of standard strength, which as anodyne, hypnotic, or narcotic passes, through the physicians, to the people.

In such a manner does this firm and others that are equally sincere manufacture the 5000 fluid, solid, and powdered extracts and concentrations of drugs that the physician not only employs but *relies upon,* and in such a manner do *not* those many other manufacturers that are insincere, ignorant, or careless.

But chemistry, even at its present best, is incapable of assaying the active principle of any drug whatever. There exist superactive principles of so delicate a texture that they break down under analysis. Therefore, Messrs. Method and Efficiency have developed a great department of physiological standardization, in which the determined and educated members thereof ask that refractory drug, not, "How much is there of you?" but, "How much can you do?"

Thus there is *ergot*. A man's wife goes bravely down to the gates of Death to pass through, or, if it may hap, to come slowly back, bearing radiantly with her the flaming torch of another life. Ergot is required. Now, ergot is a fungus growing upon rye, where it destroys and displaces the ovary of the plant. It comes from Russia, Austria, Spain, Sweden, and where not; its chemical analysis does not seem to yield reliable information, for its active constituents are not definitely understood. Finally, the physiological activity of the drug may be good, or little, or zero, just as it may chance, while after the lapse of a year it becomes unfit for use. Yet it is this substance, so utterly variable, that the physician trusts to decide the question of the woman and the child. That he may do so depends upon this most curious and interesting fact, that ergot which is therapeutically active will blacken the cock's comb of a living fowl, and that the degree of blackening may be so carefully adjusted by strengthening or weakening the drug that a standard preparation may be prepared. Consequently in this laboratory there are kept certain redoubtable roosters that continually function as standardizers of ergot (Fig. 42).

Then there is *Cannabis Indica,* or Indian hemp, the dried flowering tops of a plant growing in the East Indies, and forming in different confections the "hashish" or "bhang" of the East. This drug develops a resinous exudation that constitutes a powerful and valuable narcotic. The quantitative estimation of its active constituents is impossible in the present state of chemical science, and yet because it is perhaps the most variable drug of all *materia medica* some method of estimating its value is positively demanded. In order to standardize it, therefore, recourse is had to the fact that when it is administered to a dog of a certain weight the normal active drug of a given quantity will cause a lack of muscular control or co-ordination. The company in this way has worried out a method of so preparing its extract that the physician may implicitly rely upon its action.

Again, there is *digitalis,* and for this drug the ocular observation of symptoms is not sufficient. As it is a valuable heart tonic and stimulant, and as its chemical composition is wholly a vexed question, and because the crude drug is often adulterated, it is necessary in order to standardize it to determine the actual effect of a given quantity upon the heart's action. For this purpose an animal is anesthetized, and its heart having been fixed between the little clamping apparatus (Fig. 43), registers in the form of a curve its every movement upon a rotating smoked cylinder.

Another such substance is *strophanthus,* which is estimated by determining the least possible dose that will prove fatal to a frog of a definite weight. So determinate is this method that it has almost the ac-

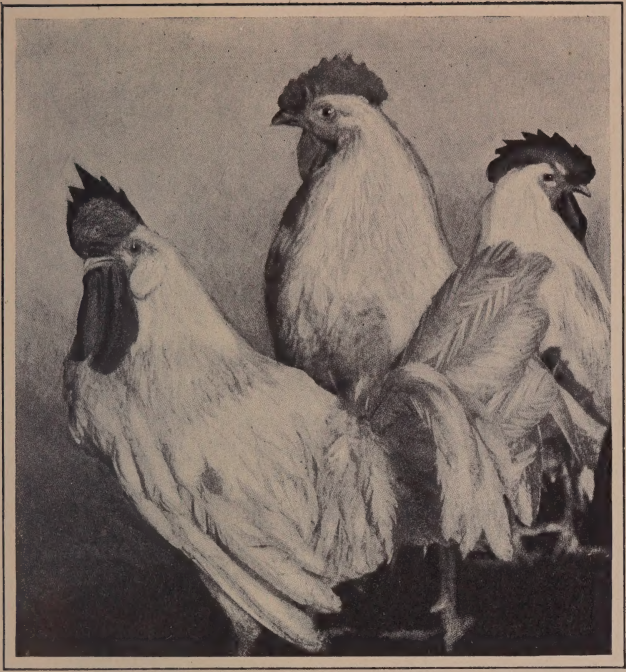


FIG. 42.—THE COMBS OF THE FOWLS ON THE RIGHT AND THE LEFT OF THE PICTURE ARE BLACKENED WITH ERGOT; THE COMB OF THE FOWL IN THE BACKGROUND PRESENTS THE NORMAL APPEARANCE

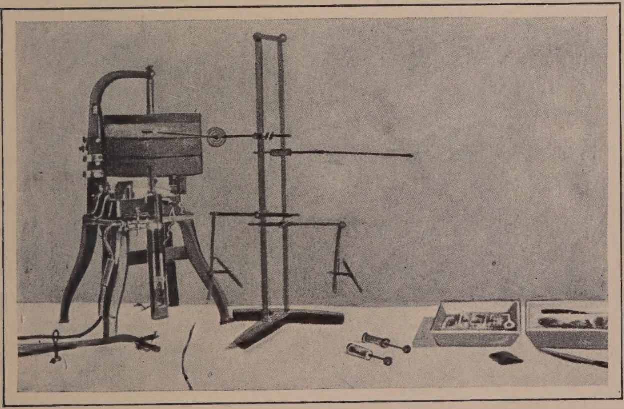


FIG. 43.—APPARATUS FOR DETERMINING THE HEART'S ACTION UNDER DIGITALIS

curacy of a chemical analysis. Thus a frog weighing from fifteen to seventeen grams is killed by a standard tincture of strophanthus in a dose of 0.00016 gram, but with 0.00015 gram it lives!

This leads one naturally to the statement that animals have by no means as many physiological idiosyncrasies as men, and that the lower they are in the scale of being, the more uniform is their action towards any one drug; they thus behave admirably as test reagents. It leads further to the statement that this experimentation is not in any sense cruel, that it furnishes no proper cause for resentment, and that in the present stage of pharmaceutics it is absolutely essential to the preparation of certain uniform medicinal agents.

This drug, strophanthus, is a new remedy, an arrow-poison coming from the heart of savage Africa, and its mention leads one, in a search for significancies, altogether away from the standardization laboratory, at the work of which we have but barely glanced, to a wholly different work of this firm—the discovery of new drugs.

Even in the early days this earnest, aggressive company recognized that among the strange peoples of the world there must be strange pharmacologies, and because of this it organized expeditions to seek out new medicinal plants. The Pacific slope of North America, the Fiji Islands, the West Indies, the Amazon River, and Peru were exhaustively searched, and thus through their efforts, though others doubtless helped, there have come into the hands of the medical profession certain drugs that are invaluable—cocaine, from the yearly production of one hundred million pounds of coca; cascara sagrada, the temporal salvation of infants the land over; guarana, for headache; yerbasanta, the balsam; grindelia robusta, the sedative; manaca, for rheumatism; tonga, checkan, pechi, jaborandi, and others.

But, and this is altogether significant, the search for new drugs among savage peoples is by no means prosecuted with its old-time vigor. The reason is not far to seek: it lies in the fact that new drugs have been discovered in the tar-barrel.

The discovery that in coal-tar there existed many substances that could be used as a basis in building up the numberless aniline dyes led to the assumption that such substances might have valuable physiological properties, and the assumption was wholly justified; the investigative research along these lines began with the attempt to attain the philosopher's stone of druggery—the synthesis of quinine. Soon it became recognized that not only the compounds of the benzene ring might have physiological properties, but that any one of the 50,000 organic compounds might have, and probably would have, properties that would affect the human organism. As a result, there is to-day an incredible number of new "synthetic" remedies introduced, through the physicians, to and into the people;

literally, every passing day sees the introduction of some of them, and lucky is he, rich or poor, in the hands of eminent specialist or general practitioner, who knows when he is not being dosed with an experiment. For, first, physiological properties do not mean necessarily therapeutic properties, and therapeutic properties over one organ do not mean therapeutic properties over all; furthermore, the enormous number of such substances forbids the supposition that there can be in every case any adequate determination of value; and, finally, the manufacture of such substances is in the hands of irresponsible people, very good, good, bad, and wicked. We would not decry the value of synthetic medicinals; they have come to us under the healing guise of *acetanilid* and *phenacetin* the fever specifics, of *piperazine* and *lysidin* with their powerful solvent powers over uric acid, and many others; so many and so valuable, indeed, that they lead us to see—in fact, to know—that it is largely through these substances that medicine may be expected to develop ultimately from an art into an exact science.

For example, there are the *hypnotics*. An ideal hypnotic is one that will produce a normal sleep as differentiated from a narcotic which produces unconsciousness by intoxication. But nobody, to-day, knows exactly what sleep is, and nobody knows exactly how a hypnotic produces sleep. To-day, therefore, an ideal hypnotic is out of the question. The first of this series of drugs arose in 1869 with *chloral hydrate,* and this substance, even to-day, is the subject of a wide usage. But chloral hydrate, while it certainly does produce sleep, has a depressing action upon the heart: it sometimes acts as a toxic agent, and, very bad, there is an extreme danger of habituation — the chloral habit. Out of the proposed substitutes for it, there are some that appear only to disappear, others linger in practice a year or two, and some bid fair to become an integral part of medicine. Thus, to mention a few of the better known, there are *dormiol, chloretone, isopral, sulphonal, trional, tetronal, hedonal, veronal.* None of these substances, however, is ideal. It may have a repugnant taste, it may be uncertain in its action, its action may be too long continued, it may have a tendency to produce profuse perspiration, convulsions, mental disturbances, gastric irritation, the formation of a habit, or a depressing effect upon the heart—always there is something of disadvantage, and it takes years of experimentation upon patients before there can be a fully determined verdict. An ideal hypnotic seems as impossible of present attainment as was, in Saxon times, that cure for snake-bite which, with a quaint touch of humor, is to be found in the Leech Book of Bald: "Against bite of snake, if the man procures and eats rind which cometh out of Paradise no venom will damage him. Then said he that wrote that book the rind was hard to be gotten."

What can the physician do? He has been known to do this: A young man lies sick unto death; he *must* sleep. Now, the physician had been reading in the advertising pages of his medical journal of a hypothetical hypnotic called, let us fancy, *idealone,* the sole substance manufactured by a firm with an aggressive and persuasive manager; the physician prescribes *idealone.* But *idealone* happens to be a severe heart-depressant, and under the influence of its hypnotic power the young man sleeps, it is true, but for a long, long time—and upon the hillside. The physician made a mistake, the foundation of which lay in this: that he did not take into account the character of the firm that made *idealone.* More and more, the physician is forced to rely upon the character of the manufacturer. The manufacturer of pharmaceutical preparations must be as careful of his reputation as a maid. Because this is so, it will be interesting to watch Messrs. Method and Efficiency in their search for a new "synthetic remedy." The search begins in their laboratory of organic chemistry. There, after it is decided by the higher powers to seek for a better medicinal agent for some one of the numerous human ills, there will be found a member of the staff, a trained organic chemist, busily endeavoring to correlate with their chemical constitution the physiological properties of all the substances used for that particular ill. This is to a slight, but very slight, degree possible. Having studied the matter in this way, he is able to think of other compounds which, because of their structure, he thinks, or rather hopes, may manifest this therapeutic property in a greater degree. Having determined upon them, then, he proceeds to make them. This may take him a month or more, but finally, as definite, beautifully crystalline or liquid bodies, they pass out of his control into another laboratory altogether—that of physiological testing.

Here they are, one after another, carefully and observingly administered to animals, and every visible physiological change is noted by efficient instruments—changes in respiration, in heart-action, in excretion, in metabolism, in their action upon nerve-centres, and others. This being accomplished after additional months of labor, some one of these substances, let us say, manifests in a superior degree a curative action upon that one human ill. It may now be supposed that the firm is ready to market its product: but not at all; a dog is one thing and a man is quite another. The firm now proceeds to send out to expert experimenting physicians privately in their employ sample packages of this substance for secret experimentation upon human subjects.

This *must* be done, for there is no other way to obtain information. Now, this discreet experimentation on the human subject on the part of the employed physicians is extraordinarily difficult, and it sometimes takes a year or two before these men hammer out a consensus of opinion. Any physiological effect upon one organ reverberates through all the others, and by-effects and after-effects are often insidiously masked or unconsciously delayed. "Moreover," as Montaigne said of the experimenting physicians of his day, "suppose the disease thorowly cured, how shall he rest assured but that either the evil was come to its utmost period, or that an effect of hazard caused the same health? or the operation of some other thing, which that day he had either eaten, drunke, or touched? or whether it were by the merite of his Grandmother's prayers?"

At any rate, even now the company does not feel satisfied, for it hereupon proceeds to send out packages of this same substance to the clinics, and it is only when the hospitals using the directions and dosage of the company's physicians obtain the same good results that the company goes to market with its new ware. When it *does* go to market, it goes, it must be confessed, with all the aggressive force of the company back of it, and with no uncertain advertising: though it ought also to be said that any advertised statement made to physician or pharmacist must first obtain the sanction of the scientific men on the staff; the company finding it advisable in this way to curb the temptations of its own advertising department. Maugre all this care, do they ever make a mistake? *They do.*

Old drugs from plants and new drugs from the tar-barrel do not, however, exhaust the company's repertory of activities. Much of its capital is employed in the extraction or elaboration of products resulting from the animal organism. Concerning the manufacture of the immunizing substances elaborated in the bodies of living animals, substances such as vaccine, antitoxin, antitetanic-toxin, and others of the kind, it is unnecessary to enter here; the reader is well aware of the absolute care and cleanliness that are quintessential to their preparation; and in the great vivarium of the company — housing horses, cattle, sheep, goats, dogs, rabbits, swine, guinea-pigs, frogs, fowl, pigeons, rats, and mice—no human care could exceed that displayed for the well-being of these animals or in the elaboration, testing, and standardizing of the products resulting from them; it is the pride of the company's heart.

Let us turn, rather, for special significance to another branch of therapeutic activity—the extraction of animal extracts, taking as a specific case the preparation of *adrenalin.*

The story opens with the little bodies known as the suprarenal glands (Fig. 44). These two little bodies, weighing each about four grams in the adult man, lie near the kidneys. It was at first supposed that they had no function, that, in fact, they were mere vestigial remnants of organs such as to-day we are given to imagining the vermiform appendix. In 1855, how-

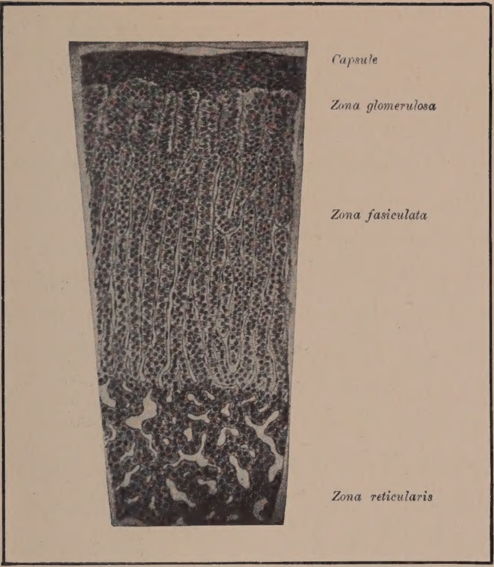


FIG. 44.—MICROPHOTOGRAPH OF CROSS-SECTION OF SUPRARENAL GLAND (SOMEWHAT ENLARGED)

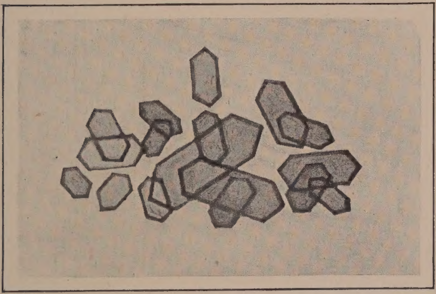


FIG. 45.—CRYSTALS OF ADRENALIN (AFTER ALDRICH)

ever, Addison showed that in the event of their becoming either atrophied or attacked by a malignant growth, a peculiar disease supervened in man, which has since been named, after its discoverer, "Addison's disease." Next, Brown Séquard showed that the removal of these organs from animals meant inevitable death. After this came the discovery that an extract of the gland contained a specific substance which, introduced into the blood of an animal, caused a marked rise in blood-pressure; and at length, in 1901, the Japanese, Takamine, working in Columbia University, though in the employ of this firm, and followed closely by Aldrich, also in the employ of the firm, succeeded in isolating from the gland of oxen, and in a pure form, its active principle. This substance was called by Takamine *adrenalin.*

Adrenalin is a light-yellow, light-weighing substance which under the microscope shows a crystalline form (Fig. 45); it has a slightly bitter taste and, temporarily, a benumbing effect upon the tongue. In practice, it is dispensed usually in the form of the chloride—adrenalin chloride. The wholly acknowledged powers of this substance are as follows: One part by weight of adrenalin chloride in one hundred thousand parts of water, or salt solution, and injected to the amount of one cubic centimetre (about half a thimbleful) into the vein of a dog, causes the astounding rise in blood-pressure indicated in Fig. 46, which is a reproduction of an actual tracing made by the dog himself. It does this partly by increasing the expansion and contraction of the heart, as indicated in Fig. 47.

Adrenalin is a physiological agent so enormously powerful that the injection of one-millionth of a gram for every two pounds of weight of an animal will cause the blood-pressure of that animal to suspend a column of water over seven inches higher than it otherwise would; so powerful that one two-millionth of a gram will produce distinct physiological results in the body of an adult man; the small doses of the homœopathists are thus gigantic as compared with those of adrenalin. This tonic increase in blood-pressure will take place under any degree of shock. Thus, Crile* succeeded, he says, in keeping alive beheaded animals for ten and a half hours through the continuous injection of adrenalin; he also succeeded through it in restoring to conscious life asphyxiated animals that had been dead, apparently, for fifteen minutes, as well as dogs that had undergone a shock of 2300 volts.

Such experiments are mislikable to do, they are mislikable even to state, but since they are, apparently, facts, they must be given. But this increase in blood-pressure is due not only to a tonic effect upon the heart, but to a constricting effect upon the blood-vessels. To such an extent is this true that one drop of a solution of the chloride having a strength of 1:10,000 will bleach the conjunctiva of the eye within thirty to sixty seconds. Because of this constricting effect, the physician and the surgeon find in it their most valued styptic. It stops bleeding, and thus becomes invaluable in the treatment of all kinds of hemorrhages; and, not only so, it prevents in large measure the possibility of bleeding, and so permits of bloodless, or practically bloodless, operations; it permits, in fact, the surgeon to work in a clear field, as, to give an insignificant example, in the removal of the turbinate bones. The literature of adrenalin therapy is to-day enormous, for it is used in a most extensive way in much special and in all general medical and surgical practice. Its utility may be taken for granted; what is sought for in this chapter is significancy, and this significancy is found in the statement that adrenalin was given to medicine by a firm of manufacturing chemists working wholly through the strictest methods of science.

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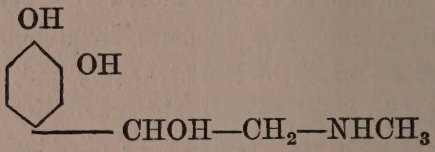
* *Boston Medical and Surgical Journal,* March 5, 1903.

To-day it is prepared on the commercial scale by this and other firms from the suprarenal capsules of oxen delivered to them from the packing-houses. The extraction of adrenalin is accomplished by a tedious and difficult process, for in any one gland there does not seem to exist more than a twentieth to a tenth of one per cent. To-morrow its preparation may be wholly from the tar-barrel, for adrenalin proved not only important to physiological chemistry, but intensely interesting to its sister science, organic chemistry. The constitution of adrenalin, for the benefit of readers chemically interested, has been determined as



and its synthesis during the last year seems to have been accomplished. At any rate, men are now able to make in the laboratory, and independently of the living animal, a substance similar to adrenalin in its chemical properties and possessed of a physiological activity just as great. So things progress through scientific industrialism. Other glands, such as the thyroid and thymus, are under large investigation in the laboratories of the company, and remedial products derived therefrom are in definite medical use; in fact, for many diseases the body seems itself to have the power to make its own medicines.

In the centre of this manufactory there are some twenty research laboratories devoted exclusively to its investigative progress. It is interesting and instructive to enter any one of them. Taking them at hazard, here is one in which there is to be found a Japanese bacteriologist whose definite, clean-cut object is to discover the best available *germicide*. In this laboratory, through the most rigid methods of bacteriology, the

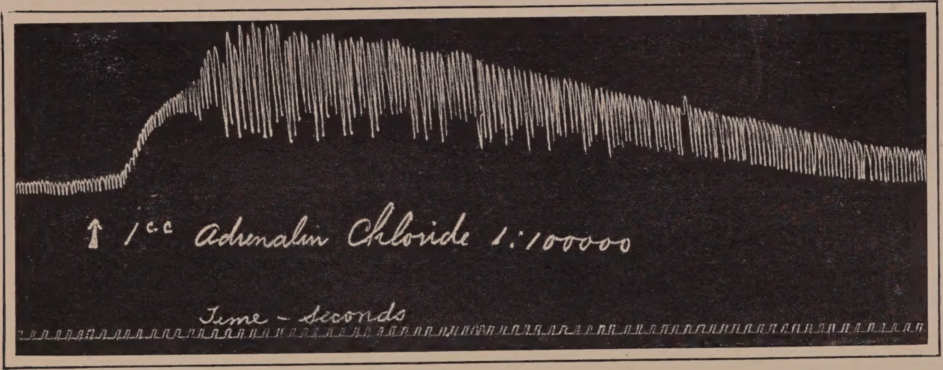


FIG. 46.—TRACING MADE FROM THE CAROTID ARTERY OF AN ANESTHETIZED DOG. THE TRACING TO THE LEFT OF THE ARROW SHOWS THE NORMAL BLOOD-PRESSURE, AND THE ARROW INDICATES THE MOMENT AT WHICH THE ADRENALIN WAS INJECTED

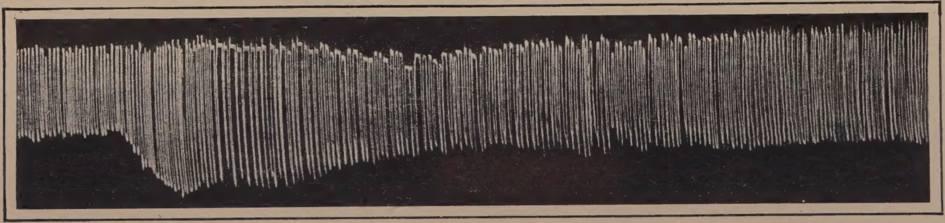


FIG. 47.—TRACING MADE SIMULTANEOUSLY WITH FIG. 46, BUT FROM AN APPARATUS CLAMPED UPON THE HEART. IT SHOWS THE ACCOMPANYING EXPANSION AND CONTRACTION OF THE HEART

investigator is carrying out comparative tests with different germicidal and antiseptic substances, and, with the germicides of other firms, upon what is apparently the most resistive of microbes, the Bacillus Pyocyaneus, the germ of festering wounds — introducing the microbes in measured quantity into the measured solution of poison, leaving them together for a measured time, and finally determining through accurate computation the comparative number of the slain.

Another adjoining laboratory concerns itself wholly with the extermination of rats. It seems that there is a certain fatal disease to which rats are peculiarly susceptible, and which is due to a specific microbe— the Coco Bacillus of Danyz. Owing to the cannibalistic nature of these creatures, this disease, when once introduced, spreads throughout the colony. In this laboratory cultures of the microbe are carefully grown, and multiplied, and transmitted to oatmeal, in which form, after their virulence has been tested, they are sold in the form of a powder to pass to all parts of the country upon the devastating errand. Since the microbes are spread upon bread or mixed with oatmeal, it is comforting to know that the disease cannot be contracted by human beings or other animals.

Still another laboratory concerns itself, for one thing, with "the typhoid agglutometer" for the diagnosis of typhoid fever, one of the greatest triumphs of applied bacteriology. The method rests upon the original discovery of Widal that the blood serum of a typhoid patient differs from normal blood in this all-important fact that when brought into contact with living typhoid germs it causes these germs to cohere into clumps or colonies, to "agglutinate." There thus arose a method of detecting typhoid fever, depending, however, upon the use of a powerful microscope and, what made it impossible for physicians, a continually renewed supply of fresh typhoid germs as test reagents. But notice the progress: Next it was discovered that this "clumping" effect of typhoid blood upon typhoid bacteria was just as efficient *when the typhoid bacteria were dead,* and, finally, it was observed that when the blood-serum of a typhoid patient was added to a liquid suspension of the dead microbes in a test-tube, these dead microbes cohered to an extent so extreme that they fell to the bottom of the tube in a mass visible to the naked, unaided eye. Because of this fact, the firm now sends to physicians in the remotest parts of the country a pocket apparatus containing an ounce vial filled with sterilized dead typhoid germs, together with accessory apparatus, so that the physician may determine whether the patient's blood will cause these microbes to "clump"—to determine, in fact, whether the suspected patient has typhoid fever.

This same laboratory is also engaged in preparing for physicians, on demand, Wasserman's new reagent for the detection of human blood. Since this test has considerable importance from a medico-legal standpoint, and since it is a bit of new knowledge illustrative of how quick is this firm to seize every chance of serving its patrons, we briefly describe it. A large and well-developed rabbit is injected intraperitoneally, at intervals of two or three days, with eight or ten cubic centimetres of human blood. Five to eight injections are given altogether, and some six days after the last one some of the blood of the rabbit is withdrawn. The blood of this "humanized" rabbit has this wholly peculiar property that when mixed with a very dilute solution of human blood it will produce, first, a clouding, and finally a definite precipitate. This "humanized" rabbit's blood thus affords an absolutely certain test for human blood (or—a significant thing—that of the higher apes) even when that blood exists in excessively small quantity, long dried, or subjected to the action of intense cold or certain chemical agents.

Without going through the other laboratories or through the enormous factory operations which result from the work of these laboratories, it is obvious enough that this barest glimpse into these manifold activities affords ample justification for what must now be said.

The coterie of individuals constituting this firm started early with the ideal of doing "ethical business" based upon science, sincerity, and wisdom. They do this same type of business to-day, because the intelligent application of scientific method is always sincere and always wise; furthermore, it always and wholly pays. It is seen in the unfeigned and spontaneous statement of one of its officials: "We did not have the face to oppose the Pure Food and Drug Law, but it will hurt our business because it will make our opponents both honest and scientific."

It thus affords an object-lesson to every manufacturer in the country, and particularly to the smaller manufacturer, who, with the coming tightening of competition, will so sorely need the intelligent application of scientific method. It always and wholly pays.

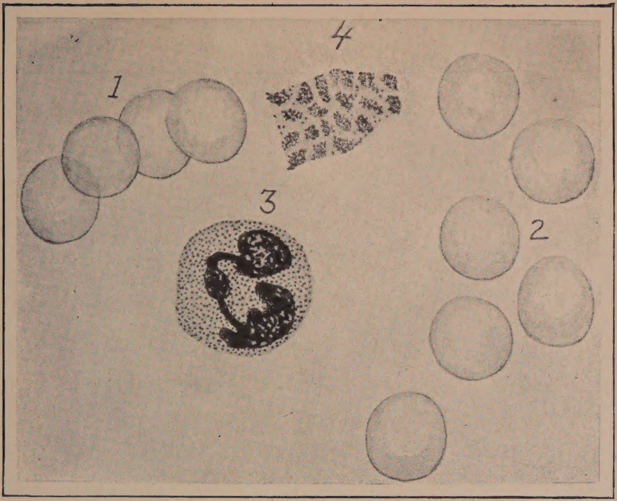


FIG. 48.—A GROUP OF CELLS FROM NORMAL HUMAN BLOOD

1 Red blood-corpuscles in rouleau formation.
2 Red blood-corpuscles, surface view.
3 Polynuclear leucocytes, or white blood-corpuscles.
4. A group of blood-platelets.

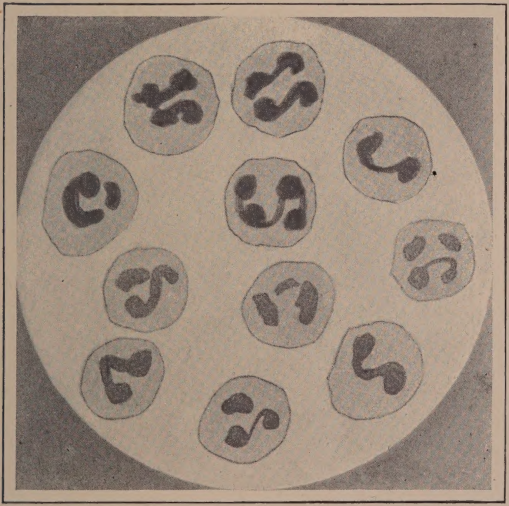


FIG. 49.—POLYNUCLEAR WHITE BLOOD-CORPUSCLES—THE SCAVENGERS OF THE BLOOD

Magnified 1500 times

X

THE NEW MICROBE INOCULATION

A DROP of human blood illustrates as well as any other substance the illimitable profundity of Nature. This is not so apparent to the eye of sense as it is to the eye of the mind. To the eye of sense, even when aided by the highest powers of the microscope, a drop of blood spreads itself out on the glass slide somewhat as in Fig. 48. There is the colorless watery liquid of the blood called the plasma, and suspended in this plasma there lie multitudes of little bodies that may be divided roughly into three kinds. Most prominent are the *red blood-corpuscles,* little button-like discs, of which there exist about 5,000,000 to the cubic millimetre; then there are the *white blood-corpuscles,* or *leucocytes,* little masses of protoplasm that have the power to change their shape and to move from place to place, and that look marvellously like the organism called the amœba that lives in muddy water; and, finally, there are the tiny bodies called *blood-platelets.* All these bodies, that to the eye of sense are hardly more than points, expand under the eye of the mind to worlds—worlds of "wingy mysteries and airy subtleties" that daze a man to study, and that are yet plainly of absolute importance to his life and welfare.

Thus, in the colorless watery plasma of the blood there exist numerous substances that, compared with their infinitesimal quantities, are almost infinitely powerful for good or evil. In demonstration of this, one, only, out of these many interesting substances shall be taken as the subject-matter of this chapter—the *opsonins.*

What, then, is an *opsonin?* The best way to define an opsonin is just to prove that there is such a thing; for its existence can only be proved by its properties, and its properties will comprise the definition. The little demonstration opens with the white blood-corpuscles, or leucocytes (Fig. 49). These bodies are shapeless masses of protoplasm that exist to the number of some 6000 to 8000 in every cubic millimetre of blood. In their function they are scavengers, for wherever in the body there is an invasion of certain kinds of microbes, to that point flock these white blood-corpuscles to do battle with the invading host. In this contest the body is a "fenced field of battle"; if the white blood-corpuscles can engulf the microbes faster than they multiply, then there is an end to the microbes; if the contrary is true, then there is an end not only to the white blood-corpuscles but to that particular *homo sapiens* that contains them. All this is true not only in the body, but in a test-tube; for if a mixture of blood and microbes be kept at a blood-heat for fifteen minutes, a microscopic examination will show that the microbes have been devoured by the white blood-corpuscles (Fig. 50). This has, indeed, been known for many a day, but always coupled with a certain assumption. This assumption was that the "gobbling" power of the white blood-corpuscles depended, to speak naïvely, on their appetite; it seemed natural to suppose this. But only yesterday, so to speak, there has come about certain knowledge that makes untenable this idea. We have shown in Fig. 50 that the white blood-corpuscles do devour microbes; we have now to see why. The following experiments are due to Wright and Douglas, to whom, practically, the honor of the discovery belongs:

Experiment 1: The white blood-corpuscles separated from the blood are transferred to a little salt solution, in which they are washed and washed, thoroughly and exhaustively, until they are pure and wholly free from every trace of the blood-plasma in which they originally lay. When, now, these washed white corpuscles are mixed with bacteria—those, for example, in *(a)* Fig. 51—and the mixture is subsequently heated in the incubator to a blood-heat, a microscopic examination shows that *nothing happens;* the corpuscles and the bacteria lie side by side like the lion and the lamb

(Fig. 52). This surprising result, apparently so at variance with what we have said above, is explained in Experiment 2: If, now, to the mixture of these washed blood-corpuscles and microbes there be added some of the liquid blood-plasma, something very decidedly happens. It is pictured in Fig. 53; the picture is similar to Fig. 52, except that the microbes are all *inside* the corpuscles; there has been a process of benevolent assimilation by which they have been absorbed into the corporation of the corpuscle.

Therefore, because of these experiments showing that the presence of the liquid plasma or serum is necessary, it is plain not only that the white blood-corpuscles cannot of themselves devour microbes, but that there must be something, some substance, in the blood liquid which does one of two things: (1) Either it must stimulate the corpuscles to devour the microbes, or (2) it must prepare the microbes so that they are fit to be devoured.

Which is the proper explanation appears in Experiment 3: If the microbes be previously incubated with some of the serum and then washed free of every trace of it, the washed corpuscles will devour them with avidity. This something in the blood liquid, then, acts not by stimulating the corpuscles to devour the microbes, but by preparing the microbes to be devoured —by apparently making them *piquant* to the corpuscles. Because of this, this substance has been

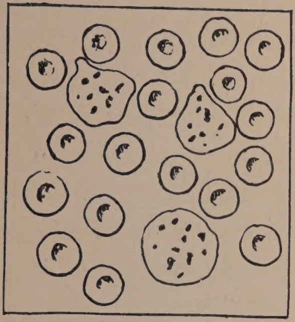


FIG. 50.—THE LARGER BODIES ARE WHITE BLOOD-CORPUSCLES, IN THE SUBSTANCE OF WHICH MAY BE SEEN THE DOT-LIKE MICROBES WHICH HAVE BEEN DEVOURED

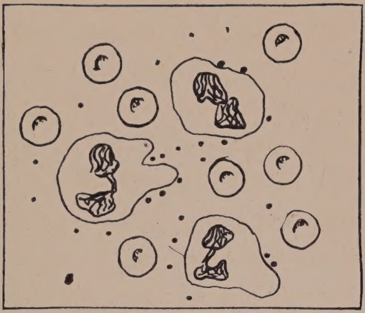
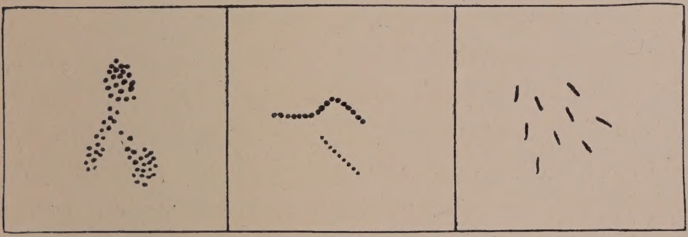


FIG. 52.—RED AND WHITE BLOOD-CORPUSCLES, AND STAPHYLOCOCCI, ALL STAINED WITH A BLUE DYE. NOTE THAT ALL THE STAPHYLOCOCCI ARE *OUTSIDE* THE WHITE CORPUSCLES. THIS BECAUSE THE MICROBES HAVE NOT BEEN ACTED UPON BY OPSONINS

Magnified about 1000 times



(*a*) (*b*) (*c*)

FIG. 51.—VARIOUS FORMS OF MICROBES

(*a*) Microbes in groups; Staphylococci.
(*b*) Microbes in chains; Streptococci.
(*c*) Microbes as rods; bacilli.

Magnified about 1000 times

named *opsonin,* from *opsono,* "I prepare the banquet." Its definition is apparent in its properties: An opsonin is a substance occurring in the liquid blood-plasma that renders microbes susceptible of being taken up by corpuscles.

The whole opsonin content of the blood is destroyed by heating the blood serum to 65° Centigrade. This is shown by the fact that if the microbes are incubated with serum which has, previously, been heated to such a point the corpuscles will have nothing to do with them. If, on the other hand, the microbes be first of all incubated with the serum at the regular blood-heat and then heated to 65°, the corpuscles *will* devour them. The last two facts, taken together, teach us not only that an opsonin, since it has a definite decomposing-point, must be a definite substance, but that its relation to microbes must be one of chemical union. From the definition of opsonin it becomes apparent that the white blood-corpuscles can have nothing to do with the proportionate number of microbes they can devour; since it all depends on the sauce, the corpuscles must be an indifferent or a constant factor. This turns out to be a fact. So long as the blood serum of one individual man be taken, and so long as the same suspension of microbes be employed, it makes no difference whether the corpuscles be taken from that man or his neighbor, or even a dog; they devour the same proportionate number of microbes.

Now, since a microbic infection in man generally spells disease, since the corpuscles are an indifferent factor, and since for the particular diseases with which we are here concerned the sole defence in the body lies in its opsonin, the discovery of such a substance has a capital practical importance that altogether transcends its intellectual interest. It is for this reason that we have been so careful to describe these experiments, in order to secure for the reader some real comprehension of the validity of the work. The immensely important question, then, is, "What has an opsonin to do with the contraction or the cure of disease?"

On proceeding further into the subject, the next important facts appear in these: First, the opsonic content in any one normal man does not vary much from day to day or during the day; next, the opsonin withdrawn from the body in the blood retains its activity practically unimpaired for days; and, finally, the opsonic activity for any one kind of microbe in all normal healthy men is approximately the same. These facts, taken together, permit the investigator to determine whether a man has, or has not, the requisite quantity of opsonin in him for the combating of disease. This is done by finding the *opsonic index,* the heart-centre of the opsonin philosophy.

It is desired to measure the quantity of opsonin present in the blood of a man who is ill with a specific disease, let us say that disease which so afflicted the

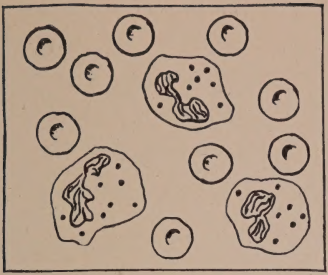


FIG. 53.—SIMILAR TO FIG. 52, EXCEPT THAT THE MICROBES ARE ALL *INSIDE* THE WHITE CORPUSCLES. THESE MICROBES HAVE BEEN TAKEN UP BY THE CORPUSCLES BECAUSE THEY HAVE BEEN ACTED UPON BY OPSONINS

Magnified about 1000 times

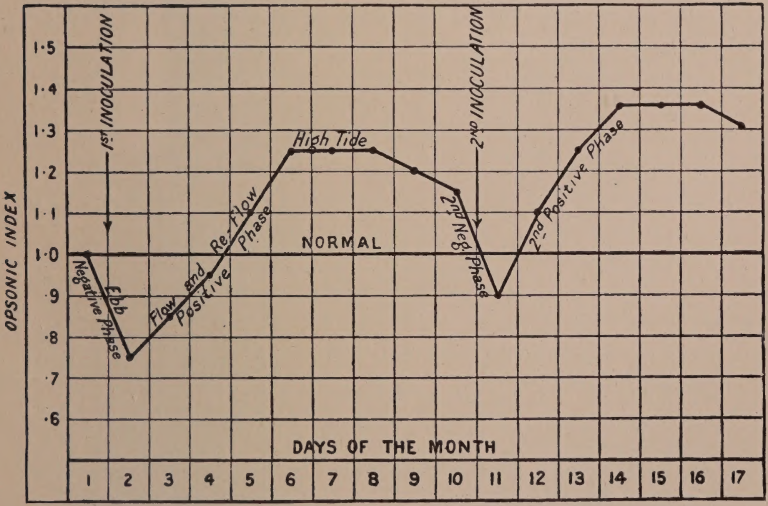


FIG. 54.—DIAGRAM OF OPSONIC CURVE—VARYING AS A RESULT OF INOCULATION

man from the land of Uz—boils. To accomplish this, the investigator first mixes his own normal plasma with equal quantities of washed white corpuscles and an emulsion of living microbes of the species called *Staphylococcus pyogenes,* the specific cause of boils. Subsequent observation under the microscope shows him that under the influence of his normal plasma many of the microbes lie engulfed in the white corpuscles.

The number of microbes engulfed by, say, fifty corpuscles is counted. Let us suppose that the number is 400; then the average number of microbes devoured by one corpuscle of normal blood is $\frac{400}{50}$, or 8. A precisely similar determination is now made with the patient's blood, and this very, very important fact drops out that, as a rule, the average number of microbes devoured per corpuscle under the influence of *his* opsonin is less than that of the normal man. It is, let us say, four. The two figures 4 and 8 thus constitute a comparison between the quantity of protective opsonin in the blood of a diseased person who is suffering from a Staphylococcus infection—namely, boils—and the blood of a normal man. In this specific example the ratio is 4:8 or 0.5:1. When, then, it is said that a man has an opsonic index of 0.5 to Staphylococcus it means that his blood has but half the quantity of opsonin essential for combating a Staphylococcus infection. Moreover, it seems not at all improbable—in fact, very probable—that this deficiency is antecedent to the infection, or, in other words, that it makes the infection possible. The opsonic index is a numerical estimation of the fighting strength of the body.

There now remains another important question: Is there one opsonin only, or more than one? It is easily possible to answer this by determining this opsonic index. Thus, with the patient considered above, while his opsonic index towards the Staphylococcus microbe is only 0.5, towards the microbe called *Bacillus tuberculosis* his index is practically the same as that of the investigator. Again, with a girl suffering from localized tuberculosis—say facial lupus or tubercular sores on the hand—while her opsonic index towards *Bacillus tuberculosis* is only 0.2, towards the Staphylococcus microbe it is as high as that of other people. There is more than one opsonin, then, and each disease which is combated in the body by opsonins has its own specific one. For this reason the title of this chapter has been pluralized into *opsonins*. Again, are there opsonins for all diseases, for "all frailties that besiege all kinds of blood"? By no means; for certain diseases the body rests upon wholly different means of protection—say the antitoxins; though it may be said that more and more diseases are being continually drawn into the opsonic fold. So far as diseases caused by *Staphylococcus pyogenes* are concerned, diseases such as furunculosis, acne, and sycosis, or those other diseases caused by *Bacillus tuberculosis,* there can be no doubt but that they stake their existence against an opsonic combat.

The all-important problem now presents itself: In the case of any unfortunate person suffering from these diseases, how can this deficiency in a particular opsonin be remedied?

This was the great problem for Professor Wright, and he has apparently solved it by the renascence of a discredited method which, illuminated by his own genius, now bids fair to become one of the most valuable assets in medicine. In a word, he inoculates the patient with an appropriate dose of the dead micro-organisms which when alive are responsible for the infective process; for example, dead Staphylococcus microbes to combat boils and acne, dead pneumococcus microbes to combat localized pneumococcus infection, dead tuberculosis microbes to combat localized tuberculosis.

The reason for this treatment and for the phenomena that are afterwards observed seems to depend on two facts. First is this, that the opsonin in the blood will unite with the dead innocuous microbes as well as with the living vicious ones; next, the disappearance of opsonin, through union with the dead microbes, stimulates the body-cells not only to the production of more, but of much more — an *excess* of — opsonin.

This is quite in accordance with the general protective methods of the body. For example, in the case of antitoxin, the injection of diphtheria toxin into the body of a horse stimulates the horse not only to produce antitoxin but an excess of antitoxin, so that by progressive inoculation the amount of antitoxin may be built up to such an extent that the horse will withstand enormous doses of diphtheria; there is therefore nothing peculiar in this stimulating power of the microbe to produce the materials of its own destruction. In this connection it may be asked, why is it, then, since the microbe is "hoist with its own petard," that it ever gets a foothold in the body? The answer is that in normal people such microbes do not get this foothold, but that in certain other people there is lacking a quality of opsonin-producing power; then, too, when the microbes do win entrance they have a way of ensconcing themselves within a fortalice of protective material, or of erecting barricades of destroyed tissue, so that corpuscles and opsonins together find difficulty or impossibility in manhandling them.

In practice, the man is inoculated subcutaneously with a standardized emulsion of dead microbes; thus, we read of Wright inoculating a patient with 2,000,000,000 dead Staphylococci, or of one of his students inoculating another patient with 2,000,000 dead pneumococci, and it may seem that it would be quite an undertaking to count so many. The matter, however, is not so difficult as it looks. We have said that normal blood contains about 5,000,000 red blood-corpuscles to the cubic millimetre; why not, then, mix equal quantities of blood and microbes and, under the microscope, count the proportionate number of each? In every cubic centimetre, then, of his microbe emulsion the investigator knows the microbic content.

The phenomena that follow the injection are of transcendent interest and importance. Let the reader remember that at any day after the injection, or any minute of the day, the investigator, with the practice of an insignificant phlebotomy, may determine the amount of protective opsonin in the blood of his patient. Now the first effect of this injection is to *decrease* the amount of this protective opsonin. This is quite reasonable from what has been said above; the dead microbes unite with the opsonin and decrease its quantity; this period of decreased opsonic activity is called the *negative phase.* During this period, however, the body flies to the rescue with the production of more, and much more; so that day after day the opsonic content creeps up, until the quantity becomes not only normal but considerably above normal; this second period is known as the phase of *flow and reflow.* Following this phase comes the phase of *high tide,* during which the body maintains this abnormally high amount of opsonin. Finally, there comes the *ebb phase,* during which the quantity of opsonin progressively declines. It will pay the interested reader to give a careful scrutiny to the accompanying diagram illustrative of these factors in the case of one particular patient (Fig. 54). He will there see that the first inoculation carries the opsonic index down to 0.75 in one day, from which point and time it rises to 1.25 on the sixth day. This high tide it maintains for two days, when it begins to ebb. Between the tenth and eleventh days, however, after the index has decreased to normal, a second inoculation is given, which is followed by a much slighter negative phase, and a subsequent rise, on the fourteenth day, of the opsonic index to the extreme height of 1.35.

As an illustration of this method of treatment, it is interesting to read of a case of "boils" reported by Wright and Douglas to the Royal Society.

"The patient was a medical man who had suffered from boils almost continually for four years. His opsonic index was 0.6 to *Staphylococcus pyogenes.* Wright inoculated him with 2,000,000,000 dead Staphylococci. On the day following, there was a diminution of the quantity of opsonins. From this point, however, there was a steady rise in opsonic power from day to day, until an index of 1.4 was reached. While the opsonic power was still high, another inoculation was given, which resulted first in a negative phase, then a rapid increase to a high tide of opsonic power equal to twice the normal. The clinical result was eminently satisfactory. After several weeks of treatment the boils quite disappeared."

The man was cured. For infections due to this specific microbe, infections such as the humiliating acne, etc., the vast amount of literature which has flowed from the laboratories of Wright, and his students, and his verifying colleagues, shows that it may be said with a high degree of certainty that such diseases may be cured by this method. Of course, the word "cured" is a dangerous one in this connection, because a sufficient time has not elapsed since the initiation of this treatment to eliminate the possibilities of a relapse. Then, again, to this statement there must be added the words *exceptis excepiendis,* for an occasional too obstinate case has been encountered.

But for tuberculosis? For *localized* tuberculosis, whether of the bones or joints or skin, the method of treatment is the same, substituting for the Staphylococcus microbes an emulsion of the triturated dead bodies of *Bacillus tuberculosis.* This statement recalls what has been said above, that Wright's treatment is the renascence of an old discredited method. And so it is, for these triturated tuberculosis bacilli are neither more nor less than the old tuberculin of Koch, about which the world got so excited some sixteen years ago.

Koch's method failed, and often promoted rather than checked the disease, because, owing to the fact that the requisite knowledge did not exist, it could not be intelligently applied. For one thing, the dose prescribed was enormously too great, and, through the union of the opsonin with the dead tubercular substance, terribly reduced the patient's powers of resistance to the living infection within him; the actual weight of tuberculosis substance administered as a dose under Wright's treatment is the almost infinitesimal quantity of one one-thousandth of a milligram! Then, too, nothing was known either about opsonins, the opsonic index, or the negative phase, and it will be plain to the reader, to take the most maleficent example possible, that a reinoculation during the negative phase would still further increase the negative phase, and that this, if continued, would drive the body's resistance to zero. It is vitally important in this treatment to watch day by day the body's opsonic index and to reinoculate in accordance with its teaching. As a result of the intelligent application of this method, many successful cases have now been recorded, representative of almost every manifestation of localized tuberculosis. Accompanying this statement there must go, however, with still greater emphasis, *exceptis excepiendis.*

But this is the *localized disease.* What about *systemic* tuberculosis, phthisis, consumption? Would that it were not so, but the fact cannot be blinked that it is another matter. This is shown in the opsonic index of pulmonary consumptives. Early cases, advanced cases that have had a complete rest in bed for a time, and sanatorium "cures" show a low or lowered opsonic index; but advanced cases under ordinary conditions show an index that is high or fluctuating. This peculiarity in consumptives finds a natural explanation in the apparent fact that the patient is continually inoculating himself with the products of his own disease—with his own tuberculin. His life thus consists of a succession of positive and negative phases and his opsonic index shuttlecocks from high to low. Since the physician cannot regulate the amount of bacterial substance absorbed from the patient's own focus of infection, he may only be adding to the danger of inoculating the tuberculin. This extraordinary variation of the opsonic index in the case of established pulmonary tuberculosis is shown by Wright in the citation of two phthisical patients whose indices had never been lower than 1. They took part in a dance; both became ill; and their indexes declined to 0.12 and 0.33, respectively; the index of another phthisical patient which had always been over 1 fell as a result of overwork to 0.2.

While, therefore, it is of course possible that tuberculin may be the ultimate panacea for the great white plague, it does by no means seem so to-day; at any rate, from a review of recent tuberculin literature, at taking the responsibility of a more optimistic judgment the writer balks. But if tuberculin cannot be justifiably alleged as a cure for established phthisis, this knowledge of opsonins, and their relation to tuberculosis, has a value that seems almost incalculable in the diagnosis of the disease in the early stages. In this connection, Dr. Wright says:

"(1) Where a series of measurements of the opsonic index of the blood is persistently low, it may be inferred, in the case where there is evidence of a localized bacterial infection which suggests tuberculosis, that the infection is tuberculosis in character.

"(2) Where repeated examination reveals a persistently normal opsonic index, the diagnosis of tuberculosis may with probability be excluded.

"(3) Where there is revealed by a series of blood examinations a constantly fluctuating opsonic index, the presence of active tuberculosis may be inferred.

"(4) Where there is only a single blood examination—if this is low, tuberculosis, either localized or systematic, may be inferred. If the index is high, systematic tuberculosis infection which is active, or has recently been active, may be inferred. If it is normal or nearly normal, neither a negative nor positive conclusion is warranted."

Remembering, then, that this man Wright and his work are together a product of the ultimate science and training of our day, if a man has a daughter over whom the doctors shake their heads: "There are no microbes—but we do not know—it is not unlikely—

we are inclined to think—that it is incipient tuberculosis"—surely it would be wise, it would be helpful, to have this opsonic index intelligently taken. But to get it *intelligently* taken is the serious difficulty. Wright's laboratories in London are crowded with students from every quarter of the civilized world—from Russia and Sweden to Hindustan and Japan—but it takes time to provide men adequately trained. Some of the great hospitals in this country have already taken steps to inform themselves by bringing over from London one of Wright's assistants to demonstrate his methods, and they are, doubtless, by this time more or less prepared. Not adequately prepared, for therein lies one great practical difficulty; the determination of an opsonic index takes more than an hour, and to spare this time, short though it seems, is of serious difficulty to an overworked hospital. Still, the General Hospital of the city of Toronto has deemed it advisable, even at this early stage of the discovery, to establish within its gates a department of opsonin inoculation, and has appointed as director of this department Dr. G. W. Ross, one of Professor Wright's most brilliant students. One of the great houses concerned with the manufacture of pharmaceutical preparations has already sent over to England, to study under Professor Wright, a member of its own staff; for with the establishment of this method of treatment there will fall upon these manufacturers the duty of providing for physicians the dead microbe inoculating material.

On every side it is seen that the attitude of the educated and intelligent part of the medical profession towards this opsonic philosophy is one of waiting, of suspended judgment, and of extreme respect.

XI

CELLULOSE: WHAT GREAT INTERESTS REST UPON A SLENDER KNOWLEDGE OF A RAW MATERIAL

IN the world of living organized beings there exists a certain substance which, like gold and silver in the non-living mineral world, is too tough a morsel for time to swallow; when pure, it rusts not, neither does it decay, and it can endure throughout all generations. This substance is called *cellulose;* it is the organic archetype of conservatism.

Unlike gold and silver, however, cellulose is the commonest of common things. When dry, more than one-third of all the vegetable matter in the world is cellulose; in fact, we may throw in all the animal as well, and find that, still, one-third of the mass is cellulose. As everybody knows, a plant is built up of microscopic cells. It is the walls of these cells that contain the cellulose. Sometimes the cells are arranged in one way (Fig. 55), and sometimes in another (Fig. 56), but however they may be arranged, it is always the sum of them that constitutes the form of the plant. Cellulose is, thus, the structural basis of the plant, the skeleton of it, and as each little cellulose cell acts as a containing-vessel for the protoplasmic aggregates whose actions and reactions cause vital activity, we may, if we like, call cellulose the very temple of life.

How the plant builds up its cellulose skeleton nobody has the remotest idea; outside of visionary speculation all we know is that it rises into being in the sun and air. What cellulose *is*, molecularly, is equally wholly beyond the comprehension of present-day man. When a man speaks of cellulose, there is a certain abatement of the voice that signifies awe. He can make in his laboratories indigo and camphor and nicotin, and a thousand other products of vital activity; he knows how their atoms are arranged, and he can arrange them for himself without the employment of vital energy; but cellulose—that is another thing. The mystery of cellulose lies in its complexity. While its formula may be empirically indicated by the little expression $C_6H_{10}O_5$, that tells us only that it is made up of carbon, hydrogen, and oxygen in certain proportions by weight. Its actual molecule may be fully a thousand times greater—let us say $C_{6000}H_{10000}O_{5000}$—and the layman knows as well as anybody else the infinite number of configurations in which it is possible to arrange 21,000 things.

Given that a certain unseen house consists of 6000 pieces of wood, 10,000 pieces of stone, and 5000 pieces of iron, and build its duplicate blindfold; this is a problem something more or less difficult than the synthesis of cellulose. What increases the difficulty a

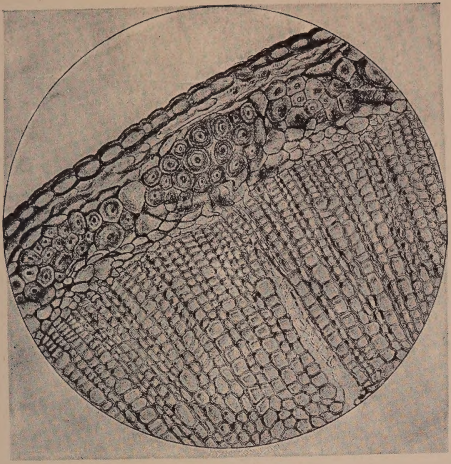


FIG. 55.—FLAX. TRANSVERSE SECTION OF STEM

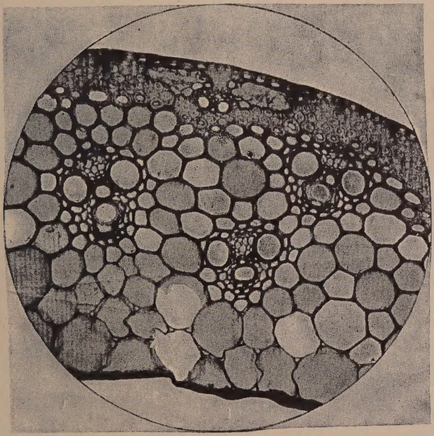


FIG. 56.—STRAW (WHEAT). TRANSVERSE SECTION OF STALK

hundredfold is the additional fact that cellulose substances and compounds are not crystalline; they are either amorphous or jelly-like substances—called "colloids" in the lecture-room and "messes" in the laboratory—substances up to within a year or two impossible to deal with, and left, for the most part, severely alone. All this indicates that however interesting this cellulose is as the structural basis of life, and however important it may be to us to build it up and split it down, cellulose research is a difficult matter.

In truth, an attack upon cellulose has all the gallantry of a forlorn hope in these days, when the universities of our country measure their men of science by the number of pages they publish. The professor who must attempt the mediocre thing he knows he can do rather than go tilting against a hundred to one, would be advised to keep out of cellulose. It is, eminently, no place for old ladies or little children. Still, even with the probability of a blank page as the result of a year's work, the temptation is great—as great as the enormous potential prizes. It is the demonstration of this, it is the notable effect upon the implements of our civilization of hacking off from the cellulose molecule here a fact and there a fact, that carries us straight into the business of our subject — the application of modern science to industry. We propose to show that every fact won from cellulose, however "academic" its importance, has been capable of industrial application, and we use this demonstration as a specific affirmation of a general principle established by long and invariable experience that there are no results of chemical investigation, however recondite they may appear, which are not in their due order absorbed into the province of technology.

The subject of cellulose is a relief; it is a relief to turn out of a world suffering indigestion from a plethora of new knowledge into a nursery of knowledge such as a cellulose laboratory, and to walk there, like Alice behind the Looking-glass, into a world where anything may happen at any time, and current chemical explanation is turned topsyturvy. But this is speaking chemically. From the stand-point of industrial utility the subject of cellulose can only be characterized as stupendous. First, let us consider those industries based upon that property of cellulose with which we began our chapter, its inertness and its resistivity to the disintegrating action of air and moisture. Here we have factories for paper, cotton and linen fabrics, thread and twine and rope, and many other substances, all of them using cellulose more or less pure.

First in importance comes paper. If one asked "the man in the street" what paper was made of, he would almost certainly say "rags," and for the fair, white sheet upon which I write this would be true, but for paper in general the answer would be absurdly inadequate, for there exists not one one-thousandth part of the "rags" that would be necessary. Our civilization exists largely on a paper basis, and in England alone it requires 650 mills, producing some 30,000 tons a week, to fulfil our needs. To feed these mills Science laid her hand on cellulose, which we cannot make, but can only take from plants. In the plant the cellulose of the cell walls, with the exception of cotton, which is unique, does not stand up pure and free and uncombined, but exists always encrusted chemically with some other substance. The substance of woody fibre is thus always cellulose X, and the problem for science was either to manufacture paper directly out of cellulose X (ligno cellulose or wood fibre), or to devise some practical method of extracting the X substance from the cellulose, and thus obtain it pure and free for paper.

Both methods are practised to-day. Paper boxes, wrapping-paper, and almost all the newspapers of the land, are made, not of rags, but simply of disintegrated deal boards pounded and mashed and amalgamated into paper. Any one of the large London or American daily papers consumes each day fully ten acres of an average forest. Such paper does not last. The wood fibre out of which it is made is, unlike pure cellulose, acted upon by light and air and water and the organisms of decay. This is bad, but not wholly bad, for most of the literature appearing on this paper is made as mechanically as the paper itself, and it is fitting that it should be as ephemeral in fact as it is in nature. But sometimes Literature (with a capital L) appears on this wooden foundation—and that is a tragedy. Had Mr. Pepys written his admirable diary upon what we call "scribbling paper," we would, to-day, have no Mr. Pepys.

England alone, every year, imports some 350,000 tons of this mechanical wood-pulp to turn it into paper. She imports also some 200,000 tons of what is called "chemical wood-pulp"—*i. e.,* wood from which the encrusting impurities have been chemically removed, and which consists of cellulose almost pure. For chemistry has succeeded in doing this, and it is doubtful whether any chemical discovery of modern times has had a success so spontaneous and so immense in industrial value. In fact, the success has been achieved in several ways. Possibly the sulphite method, which we take for illustration, is the most typical.

Factories using this method exist nearly always in the neighborhood of pine forests and deposits of iron-pyrites. The sulphur dioxide obtained by roasting the pyrites is passed up through a high tower packed with limestone, down through which a stream of water trickles. Under these conditions the burnt sulphur gas enters into combination with the lime, and ultimately constitutes a liquid consisting partly of free sulphurous acid and partly of bisulphite of lime. This liquid passes into a "digester," filled with wooden chips, where, at a temperature of about 117° C., it attacks and demolishes everything in the wood but cellulose. The cellulose is thus left free and uncombined and, after being bleached by chloride of lime, pure. Thence it passes as cellulose to the paper-factories, and emerges there as paper for books so good that only an expert can tell the difference between it and a paper made from the cellulose of rags. To such an extent are the forests of our country being swept up into newspapers and books that it urgently requires supervision; the only comfort, apparently, being that there is a cycle of reaction by which the newspapers and books will ultimately be burnt, or will decay, into carbon dioxide, which will be absorbed by the forest into new wood, which will appear again as newspapers and books *ad infinitum.* For the cellulose from wood is different from the cellulose from cotton or linen—it *does* decay, or at any rate it *may* decay—certainly it is not so strong.

Just why cellulose from wood is not so good as cellulose from cotton we cannot explain by current chemical theory; we know only that the cellulose molecule seems to carry upon itself the cicatrice and weakness of the structural rupture by which the cellulose was extracted.

There is a brilliant opportunity for somebody to transform wood cellulose into the lasting cotton-cellulose variety. There is an opportunity equally great for devising some method of turning into utilizable chemical products the portion of the wood torn away from the cellulose. This constitutes fifty per cent. of the weight of the wood, and at present it goes down the drains—an example of horrible waste. In the paper-factories themselves chemistry is applicable in a variety of ways. For example, there is a question of *sizing* the paper in order to make it resistant to ink, there is the question of making paper water-proof, there is the gentle art of making the paper appear other than it is by loading it up with extraneous material. In such matters as these chemistry is entirely applicable, and the present practice unfortunate. Owing to the fact that the paper-makers have in the cellulose pulp that comes to them a magnificent example of the applicability of chemistry, it is interesting to compare the enormous output of paper indicated above with the chemists employed in its manufacture. The whole paper trade of England employs at least ten chemists at salaries actually exceeding in certain cases five hundred dollars a year!

Turning now to cotton, we find ourselves in the presence of an industry which may be considered almost to have reached a condition of terminal perfection along mechanical lines. The beautiful machinery for cotton fabrication is a marvel of human ingenuity. But, however mechanical cotton fabrication may appear, since it deals with the elaboration of a natural product, it rests upon a chemical basis; and since in the United Kingdom alone there are some 42,000,000 spindles working it up to the extent of a billion and a half pounds a year, any little chemical fact concerning cotton manufacture is bound to have its importance. Let us illustrate this by one small fact discovered by John Mercer; it was known for thirty years before it was deemed significant. If a piece of cotton—which, it must be understood, is pure cellulose — be placed in a strong solution of caustic soda, the soda causes the cellulose to unite with a molecule of water, the cotton shrinks nearly twenty per cent., it becomes nearly fifty per cent. stronger, and it takes on a greater dyeing capacity.

But this is not all; if, now, the cotton fabric be stretched tightly upon a framework so that the shrinkage mentioned above cannot take place, the soda solution brings about a transformation in its constituent fibres in such a way that the fabric assumes over its surface a silken sheen. The beautiful fabrics so manufactured are known as mercerized cotton, and this manufacture now amounts to an enormous industry. Just one little fact established this business, and since the molecule of cellulose is a forest of complexity swayed, within certain limits, by every breath of chemical influence, the number of potential facts is indefinitely large. We find in recognition of this that the textile companies "occasionally employ a chemist at an economical salary."

The very business of dyeing, which is all chemistry, is founded upon another little chemical fact, that the cellulose molecule contains, feebly, acid and basic groups which unite with the dye and hold them fast. As to the nature of these groups, we are perfectly ignorant, though their discovery would be vastly important. But some dyes refuse to cling to the cellulose fabric, and so advantage is taken of still another empirical fact of cellulose, that on digesting it with certain mineral basic salts—for example, tin—the cellulose entangles the salt within its molecule, with the result that the cellulose clings to the salt, and the salt to the dye, and so our cloth is colored in despite. This process is called mordanting.

Another important cellulose fabric is linen. The Irish flax trade employs over 800,000 spindles, and the value of the linen exports amounts to $25,000,000 a year. Chemically, a linen fabric and a cotton fabric are identical substances, for they are both pure cellulose; mechanically and practically there is a huge difference, which depends upon the form and structure of the fibres. Linen cellulose is prepared from flax in a much more complicated way than cotton is obtained. The cellulose in the flax is intricately combined with other substances, and one of the most valuable discoveries for this industry would be a thoroughly feasible method of separating out the bast fibres in some other way than by the traditional one of steeping the flax in stagnant water until the separation is accomplished by a rotting fermentation.

We omit here other chemical possibilities of flax cellulose in order to pay a resentful reference to the process in use for the cleansing of both linen and cotton textiles. Laundry-work constitutes in these times an enormous special industry. It is computed that in England the average family spends five shillings a week in washing, and since there are 40,000,000 people, with five persons to a family, the whole country must spend £2,000,000 a week for laundry. It is high time this work was organized along sensible chemical lines. At present the laundry practises its trade with a joyous ignorance of the properties of cellulose and of the chemical agents it employs, and it is admirable only as it increases the consumption of textiles. Why do they not use in a modified way the same process for cleansing cotton or linen that the manufacturers of it use for bleaching and finishing it? It is to be hoped that some day some man will write a chemical "Song of the Shirt" that will establish in the minds of laundrymen the conditions that make for its longevity.

Another interesting cellulose fibre is that of jute, which plays the humble part of providing us with sacking, and wrapping and baling cloth, as well as with the lowest grade of floor-cloths, in which it acts as the foundation for the linseed-oil mixture that makes up the ornamental element. Not a very elevated function, truly, but useful to such an extent that the city of Dundee alone imports raw material to the value of $35,000,000.

Still another fibre that obtains a peculiar interest, from the heart-breaking mistakes and discouragements of its initiation, is ramie, or china-grass. This plant, grown in India and southern Italy, yields a long, lustrous fibre, which is cellulose *in excelsis.* The difficulties concerning its manufacture have been overcome, and the industry is now properly deliminated and on a basis of sound, practical utility. It is used for twine, sail-cloth, fishing-nets, dress goods, tapestry, plushes and velvets, and ladies' wraps and shawls. It is inimitably good as the cellulose basis of incandescent gas-mantles.

Finally, there is hemp, and with its mention we close the list of fibres used for woven material in Europe.

For the twine and rope industries there are used, in addition, the fibres of manila, sisal, phormium, and a few monocotyledonous plants. We mention them simply in order to place beside the summation of them the following statement.

There exist in the world approximately 110,000 species of flowering plants. The stem of no one species is identical with any other; they are of infinite variety, possessed of infinite fibre-making possibilities. Out of them all, through chance or through blind tradition, we use the fibres of those mentioned above. Is it not possible that, in spite of the rigorous requirements for matriculation into the fibre-using industries, there might be some that for special purposes are somewhat better?

We have so far considered cellulose only from the stand-point of the merit of its inertia, only from its negative side, and we now turn to consider it as a chemically active body. And in what follows it is immaterial what form of cellulose is used, whether from cotton, linen, wood-pulp, or what not.

For a certain reason that nobody knows anything about, cellulose will dissolve slowly in a hot concentrated solution of zinc chloride, with the production of a sticky syrup. This syrup, when forced through a narrow orifice into alcohol, precipitates a thread which is carbonized, and utilized in these days for the manufacture of filaments for incandescent electric lights. Again, it is used as "vulcanized fibre" by soaking paper in four times its weight of the concentrated solution, and working up the gelatinized mass into blocks and sheets, which are turned into handles and the backing of instruments and many other objects. For a reason equally unknown, cellulose will dissolve better in ammoniacal cupric oxide. This solution constitutes a blue syrup of very high viscosity, from which the cellulose may be precipitated by the addition of agents such as alcohol or common salt. This method of dissolving cellulose has important industrial applications. For example, paper or cotton fabrics are passed through the solution, and so "surfaced" by a film of the gelatinized cellulose which retains its copper constituent in such a way that it dries of a bright "malachite" green color. Fabrics so surfaced become water-proof and immune from the attacks of insects and mildew. Many of the heavy coverings used for express-wagons and "busses" are made of these "Willesden" goods—so called from the town in which the company has its seat. If the fabrics so treated are rolled or pressed together when in the gelatinized condition, they become welded to form an extraordinarily thick and resistant texture. During the South-African war compound papers of this manufacture were employed as barricades, for they are bullet-proof.

Under proper conditions of treatment, cellulose will dissolve, also, in acetic acid (acetic anhydride) with the formation of a viscous liquid which dries into films of great tenacity and high lustre. Owing to its waterproof character and to the fact that it is a non-conductor of electricity, this cellulose acetate provides a splendid insulating material for electrical wires, and its manufacture for this purpose is now an established industry.

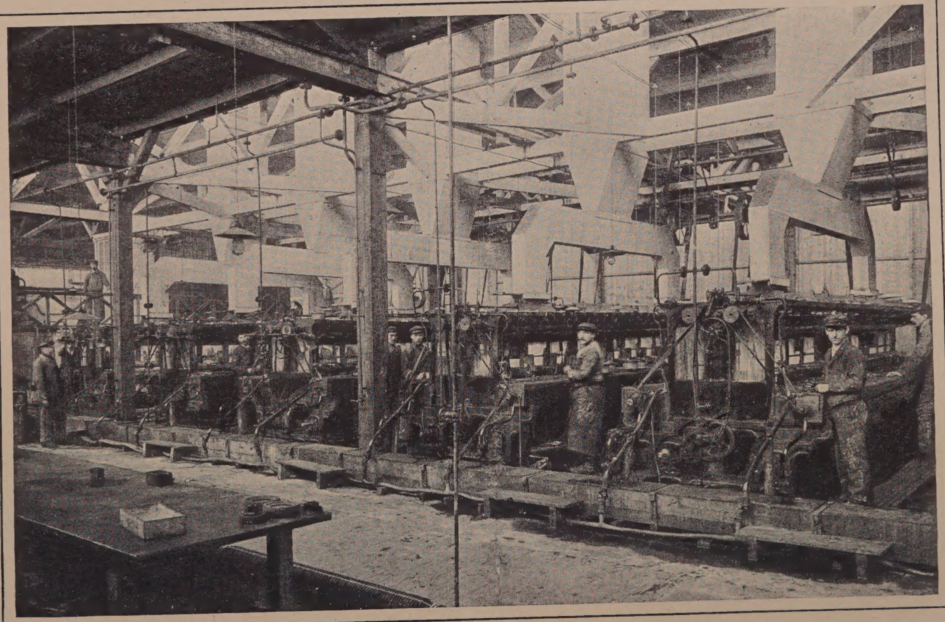


FIG. 57.—INTERIOR VIEW OF "VISCOSE" FACTORY

Perhaps the most interesting solvent for cellulose is that discovered by Cross and Bevan. When "mercerized" cotton, which we have already described, is exposed to the action of carbon disulphide the substances unite together, with the formation of a substance which, chemically, rejoices in the name of alkali-cellulose-xanthate. Popularly it is called "viscose," and it constitutes a remarkable achievement in cellulose technology. Viscose is perfectly soluble in water to a solution of extraordinary viscosity. But its most interesting property—the property that makes it valuable — is the spontaneous decomposition of this solution. You start with alkali, carbon disulphide, and cellulose, and after leaving for a short time the viscose so formed, you get alkali and carbon disulphide and cellulose again—an interesting cycle of change. The cellulose thus regenerated is hydrated and highly plastic. It is applicable enough for moulding and casting into all kinds of useful forms, and for the manufacture of thin, tough, transparent films that possess a high degree of elasticity. These pure cellulose films are finding a useful application for tying over the stoppers of bottles and, scientifically, for making dialyzers. They will resist three atmospheres of pressure, and, consequently, they form a perfect hermetic seal. But the great use for "viscose," the use in which its factory management is wholly preoccupied, we shall refer to later on.

Such are the solvents for cellulose; but there are other substances with which it reacts in a manner wholly different. For instance, there is sulphuric acid. which, when concentrated, attacks cellulose in force and completely breaks up its formation—disorganizes it into grape-sugar. We know of no industrial corporation manufacturing grape-sugar by this process, but we do know of one that proposes to make alcohol by it—for the transformation of grape-sugar into alcohol is relatively easy.

The action of nitric acid is wholly different from sulphuric. It is additive in its nature. Thus, if we add to cellulose-cotton nitric acid in the proper proportion (or a mixture of nitric and sulphuric acid), the state of Nirvana in which the cellulose has so far complacently rested vanishes, and while the cotton looks as innocent as ever, it has suddenly assumed a supreme power of settling international disputes or (since it is so easily made) of forcing in upon despotic rulers some regard for their responsibilities. We know this substance as cellulose hexanitrate or, commonly, guncotton. This guncotton is a "high explosive," good for blasting, for torpedoes, and for military mines and bombs. To modify it down into a "propulsive" explosive it is mixed with nitroglycerin, and it thus becomes "blasting gelatin," and the "smokeless powders" used for military purposes, such as "ballistite" and "cordite."

The American government, though, prefers to use, both for army and navy, a smokeless powder made solely of cellulose nitrate of a certain strength of nitration. For "sporting" powders, also smokeless, the cellulose nitrate is mixed with barium nitrate and a certain proportion of camphor or nitrobenzene. Such are the "E. C.," "S. S.," and others. Altogether, the manufacture of explosives based upon the nitrates of cellulose has assumed enormous proportions. In the United States, in 1900, there was an output of 3,053,126 pounds of smokeless powder alone, worth at the works $1,716,101, and we may look with reasonable confidence to a time in the near future when black gunpowder will have become as effete as the bow and arrow.

But the cellulose nitrates have uses not merely *destructive*, but *con*structive. The Hyatts of Albany discovered the curious little fact that the lower nitrates of cellulose are soluble in solid camphor and alcohol (no chemist would ever have thought of such a thing), and, furthermore, they discovered that the resulting product, under proper heat and pressure, could be worked like rubber. Thus came to us "celluloid," which is now cut into sheets, stuffed through die-plates, moulded under pressure, turned, and the like, into a thousand types of products to amuse or minister to mankind, and of a value of nearly $4,000,000 a year in the United States.

The fact that “Celluloid” is a sister of Guncotton does not mean that she has all the eccentricities of her big brother, though in the intimacy of the fireside it is wise to recognize the relationship. If instead of dissolving these lower nitrates of cellulose in camphor they are dissolved in a mixture of ether and alcohol we obtain collodion. This is a useful substance, finding employment in a multitude of ways—as a vehicle for medicine, as a substitute for sticking-plaster, for bandages, and in photography simply indispensable in a dozen ways. Altogether, the industries based upon the nitrates of cellulose form a remarkable contrast to the industries based upon the *inertia* of cellulose. They constitute a picture of what an industry ought to be, carried on, as they are, with a high degree of precision, and with mechanical *and* chemical efficiency.

We are now in a position to consider, briefly, the use of cellulose solutions in the production of one of the great triumphs of technological science—artificial silk (Fig. 58). In making artificial silk there are solvents for cellulose. To-day the favorite method is that of Count Hilaire de Chardonnet or Dr. Lehner. Bleached cotton (cellulose) is treated with nitric acid to form a cellulose nitrate of a strength somewhat under that of guncotton. It is then pressed and thoroughly washed. Next, it is dissolved in a mixture of ether and alcohol, and filtered, as collodion, into a reservoir. From this reservoir it is forced, under a pressure of some 650

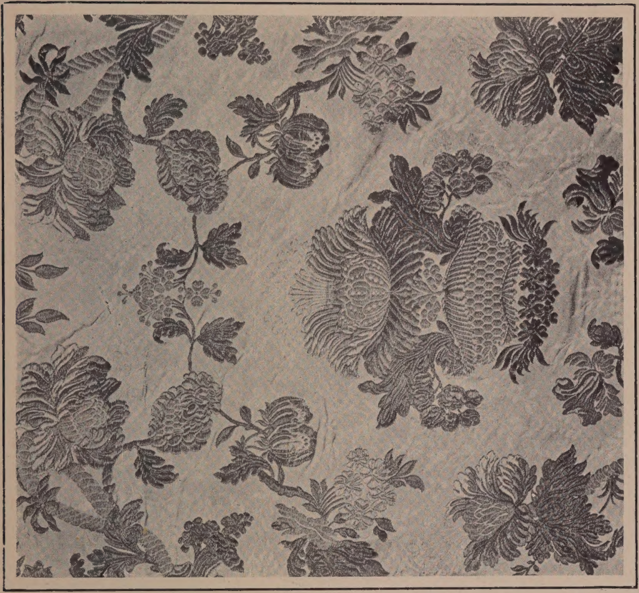


FIG. 58.—A CHARACTERISTIC FABRIC OF ARTIFICIAL SILK BROCADE

An artificial silk pattern on a ground of natural silk

pounds to the square inch, through capillary tubes, whence it issues as a fine thread. As the thread issues into the air it solidifies, is conveyed to a bobbin by the operative, and, mingled with other threads, ultimately arrives in the condition of a silky, lustrous skein. In this form, however, it is still, more or less, guncotton, and wholly unsuitable for ladies' gowns. It must be denitrated, and for this purpose it is passed into sulphydrate of calcium (one method), by which it reverts to pure cellulose, substantially identical in chemical composition with the cotton from which it started, but differing widely from it in appearance; for now, to all appearances, it is silk, fine, and actually more lustrous than natural silk.

Another method in manufacturing practice starts with cellulose dissolved in ammoniacal cupric oxide; another, with its solution in zinc chloride; but, possibly, the most formidable rival to the process we have described is the " viscose " method by which wood-pulp is caused to react with caustic soda and carbon disulphide, and, in the form of xanthate, spun and consequently decomposed into cellulose. In all these methods, outside the chemical value of the product, is the interesting fact that no matter into what combination the cellulose is tortured—whether into nitrates or xanthates—the plasticity of the product is the plastic power of cellulose, the same power that functions in cellulose as the structural basis of plant life.

Artificial silk is to-day used to a large extent for braids and such classes of trimming, where it is much more brilliant than natural silk; for covering electric wires; for mixing with other textiles, particularly silk, and also as a fabric alone and on its own merits. It does not, however, parade the shops as such, for while the shopkeepers are almost inevitably in possession of artificial silk, they do not know it. The amount of artificial silk manufactured in Europe amounts to five tons a day, and the demand greatly exceeds the supply. The total amount of natural silk manufactured in Europe does not exceed twenty-five tons.

A pine-tree is worth $10 a ton; cut and stripped, it is worth $15; boiled into pulp, it is worth $40; bleached, it is worth $55; which, turned into viscose and spun into silk, is worth $5500. From these data it is seen that cellulose has interesting possibilities. Yet so far we have entered but on the fringe of its possibilities. Prospects and indications of a mine of wealth lie everywhere. For example, cellulose is, within certain limits, extraordinarily sensitive. A certain substance known as diazoprimuline is but slowly affected by light; but place it upon a cellulose paper and it is (for unknown reasons) spontaneously decomposed by sunlight. From this fact arises a process of "positive" photographic printing. Again, cellulose seems, to a certain extent, a conductor of electricity. Attach a coin to the positive end of a battery and a sheet of moist paper to the negative end; press the coin on the paper, and, after suitable development, the image is formed upon the paper. Or, again, reverse the polarity and press the coin on the paper. No result is apparent, for the image is latent; but even after the lapse of months treat it with a silver salt and developer, and there will at once be seen the image of the coin. It is by no means impossible that this little fact will lead to a method of electrical printing without ink.

In all sorts of ways cellulose is an "active" substance if we but knew how to take advantage of it. The plant knows, for in certain cases it must break down in its cell walls in order to utilize their contents. Certain enzymes, also, are able to react with it, for, occurring as they do in the digestive tracts of animals, they are able to resolve it. Then, as for the synthesis of cellulose, while we cannot accomplish it ourselves, it is, nevertheless, being done. Thus, in beet-sugar juice cellulose is spontaneously formed through the action of some certain enzyme; while among the microbes, the baterium xylinium can manufacture it out of grape-sugar.

The object of this chapter is to show that the cellulose industry, in common with other industries that have the greatest influence upon human affairs, is developed upon an exceedingly slender knowledge of the raw material, and that it behooves the manufacturer on the one hand and the centres of technical education on the other to recognize this. Specifically for cellulose, if the technical departments of the universities would remove from their windows the young men who stand there desperately waving their arms for employment in the dye industries, and would, instead, turn them in upon a study of the material upon which the dye is placed, it would greatly conduce to the profit and satisfaction of the manufacturer and, incidentally, to our own.

The cordial thanks of the writer are due to Mr. C. F. Cross, of London, the dean of cellulose science, for the information contained in this paper, and to Mr. J. F. Briggs, his assistant in the laboratory, for his many interesting experiments.

XII

INDUSTRIAL FELLOWSHIP: A SCHEME BY WHICH A MANUFACTURER MAY SOLVE HIS PROBLEMS

THAT all industries have problems of a scientific nature may readily be discovered by simply inquiring of any manufacturer whatever. In these days he will not only admit that he has these problems, but he is apt to complain, even bitterly, that he cannot find the men to solve them, and, moreover, that their continued lack of solution means, imminently, loss or failure to his individual instance of the industry. In the past few decades, while these problems were present, ever and always, they were masked, or, at any rate, their importance was masked, by the wealth of raw materials that lay everywhere at hand; by an aggressive tariff, that concealed from the manufacturer the practical presence of the problems; and by a certain facility in what may not unfairly be called business intrigue, which enabled him to supplement the waste in his factory by combinations for the elimination of competition; finally, the needs of the population have been so open-mouthed and hungry that the cruel edge of competition lay long unsharpened.

Now, however, in all industries, conditions are radically changing. The unexampled and wasteful production of the country bids fair to result in overproduction; in the practice of business intrigue each manufacturer has sharpened the face of his rival to a razor-edge; the wealth of raw materials has in large measure been aggregated into the holdings of a few men, who release these products to the manufacturer only at an onerous and distressful rate; the tariff, high as it is, is still unable to exclude many articles of foreign manufacture made under the intelligent supervision of modern science; and, for we live in parlous times, the tariff, itself, on its present high pinnacle lies in unstable equilibrium. The steady growth in the introduction of articles of foreign manufacture made with the aid of modern science is no mere silliness of the imagination. To one who, like the writer, has spent a year in Europe in the continued investigation of the extent to which science is applied to modern industry, the situation could only be characterized adequately through utterance that would be sensational.

The Germany of the days prior to the Prussian conquest has passed away and the new Germany is a Germany of workshops; and workshops, too, in which, in the intelligent application of means to ends, which constitutes the scientific method, in the eagerness to harness new knowledge to their service, and in a willingness to spend money in intelligent experimentation, there is demonstrated a condition of almost perfect functioning. In France, also, though not with the same method, but in a spirit as eager and intelligent, there is the same turning over into sensible scientific conduct of the traditional industries and the same activity in the establishment of new ones. In Italy, too, long deemed a land of languorous ineptitude, the scientific spirit has stirred into active being a multitude of new industries. Even in England there is abroad in the land the spirit of applied science.

Nowhere else, however, is there in evidence the same system of co-ordination and co-operation in industry as there is in Germany. The universities are co-ordinated with the industries, and so are the banks and the great steamship companies; all of them constituting a system of co-operation so observable that it forces the conclusion that it is not the unconscious outcome of the German character, but the result, rather, of an active and conscious plan.

Apposite to this statement, and indeed typical, is the case of a German university professor who discovered a new process. His first step was to present it to the experts of one of the great factories concerned; his second was to present it to the Deutsche Bank, which employed its own experts to report on the validity and practicability of the process. As a result, the professor with his discovery, the Deutsche Bank with its funds, and the company with its immense facilities for investigating the discovery on a large scale, formed a little company of three for the exploitation of the process. How impossible would be such an arrangement in this country!

Thus it is in Europe; but what about America? It is no mistake to say that American manufacture is a chaos of confusion and waste. It is no mistake, either, to say that the American manufacturer now knows it. The confusion and waste, it should be said, are chemical, not mechanical. Along the lines of mechanical contrivances America need acknowledge no peer. But mechanical contrivances are but a small part of the operations of modern industry. Since every manufacturer deals with the modification of substance, and substance is the business of chemistry, every manufacturer is just exactly to that extent chemical. That this fundamental truth has not, in the past, been recognized is due largely to the fact that manufacturers of the last generation were, generally speaking, men endowed with great natural abilities but of small education — men who, starting as factory "hands," worked themselves up through the grades of foreman and superintendent to managerships and presidencies. To such men, science and the scientific method meant literally nothing; it was outside their ken, and they had all the impatience and disdain of the "practical man" for what they called the "theoretical fellow."

With the growth of the combinations of capital, however, and with the coming of a schooled generation of business men, matters have assumed a different aspect. Naturally enough, the large organizations of capital have been the first to appreciate the working value of the leaven of new knowledge, and it is in marked degree due to this appreciation that they have successfully differentiated their factory processes from those of small companies or individual manufacturers. The small manufacturer, failing in the stress of competition, often ascribes to business intrigue and combination a competitive success that actually belongs to modern chemistry. There is, as a matter of fact, a singular difference to-day between the factory practice of different companies in any one industry. This is for the reason that the larger companies, while employing expert scientific advice with huge resulting economies, keep their improved processes strictly to themselves, for, obviously, in applied science, it does not pay to tell. The result is a situation that to the smaller manufacturer grows more and more intolerable.

There is a question that has come to the writer out of every quarter of the English-speaking lands, and from trust organizations and small manufacturers alike: "How can we utilize modern knowledge?"

This question, the writer believes, has found its answer in a practical form in a new relation which he has suggested and initiated between the University of Kansas and the people of the country. It lies in giving the manufacturer the privilege of founding in the University a Temporary Industrial Fellowship for the investigation of a specific problem, the solution of which would mutually and materially benefit both the manufacturer himself and the public.

The consistency and propriety of this aid are seen in the accepted dictum that the University stands for the whole good of man—for the *uplift* of man. The absolute function of the University is not only the increase and diffusion of knowledge among men, but of *useful* knowledge. It must be remembered that it is only through useful knowledge that the people have gained the material blessings of our new civilization. Furthermore, it must be remembered that every useful agent in our new civilization is the product of an industry, and that it is only through the industries that these new products of civilization can go to the people. New mechanisms — such as the telegraph, the telephone, the electric light, the X-ray bulb—new medicines, new dyes, new steels, new and improved products that surround us on every side come to us only through the industries.

People confuse the blessings of the products of industry with the mixed blessings of the exploiters of industry. Every discovery utilizable by industry is a thread in the fabric of a future and more gracious civilization. The exploiters of industry, on the contrary, are a phenomenon belonging of necessity only to our age. Future men may, and doubtless will, modify and control their powers or altogether eliminate them; but, in the industry which they exploit, there lies the whole hope of the betterment of the world. For science, waste-abhorring, will introduce such economies; and science, the spirit of intelligence, will discover such new processes and agents and powers that man, in the far future, but inevitable, readjustment, will find through science the chance to live. Consequently, the University may with entire propriety lend itself to the increase of useful knowledge, all the more since it forwards this useful knowledge by simply affording the manufacturer the opportunity of helping himself.

That the University can, actually and practically, forward the progress of industry is seen in the consideration of two facts. First, is the application of new knowledge: the problems that may be solved by the layman in science, even though that layman be a foreman in the factory, have practically disappeared —problems having obvious and apparent answers have all been solved. Again, owing to the continuous acceleration of modern knowledge, the field of science, so long as it is not compared with that which still remains to be discovered, is prodigious in extent—and it is only in the universities that such knowledge is practised and known. It is this knowledge, born and bred in the universities, that is creating industrial revolutions. It may be said on this point that the industries have in their employ their own chemists and other men of science, but such a statement would be barely a partial truth.

It is true that the large trust organizations—that is, their real, and not adventitious, success — rests upon the service of these men. As for the smaller manufacturers, however, they employ practically none; their "chemists" should be quotation-marked to mean laboratory boys, trained only to do one testing operation over and over again. Even those men of unquestionable scientific training that are at present employed by the factories are by the very fact of that employment incapable of solving its problems. As one large company recently informed us, such men "cannot see over their own fence," they "cannot see the wood for the trees," they "are killed by their own routine." To take a specific case: A chemist employed by a glass-factory may, sensibly and accurately, analyze the furnace-gas and the soda and lime and sand used in the making of glass, but he could not possibly determine the science of glass-making; that kind of a service was rendered by professors from the University of Jena. The fact is that, in these days, the really important problems can only be solved by the rendering of aid from outside—by men attacking the problem with a perfectly open mind and armed with a wide range of new facts apparently unrelated but potentially applicable. We see this in the actual facts of the case—that it is from the large universities of the world that industry has received in recent years its most valuable gifts. It is well within the mark to say that, during the last ten years, three-fourths of the discoveries of industrial importance have emanated either from the universities or from men whose knowledge was obtained therein.

But the beneficence of the University extends not only to the solution of an industrial problem, but, also, to the furnishing of men. That "good men" are scarce is, of course, a truism; but it is terribly apposite in these days. The modern manufacturer advisedly economizes in everything but salaries, and the very considerable salaries paid to good men are ample evidence of their rarity. Now, the purlieus of adolescent "good men" are the laboratories of the University. There it is that men are "tried out," and there it is, too, that men are known better than they know themselves. When, therefore, the University accepts from a manufacturer the foundation of an industrial fellowship, it not only provides an expert intense attempt to solve a problem by the application of the newest of new knowledge, but, as well, it provides for that industry a "good man," whom the industry would do well to cherish, or, at any rate, the best man available.

The character of these Fellowships is best demonstrated by a specific case such as we give below:

The A. B. Industrial Fellowship.

For the purpose of promoting the increase of useful knowledge, the University of Kansas accepts from *The A. B. Company, of Chicago,** the foundation of a Temporary Industrial Fellowship to be known as *The A. B. Fellowship.*

It is mutually agreed and understood that the conditions governing this Fellowship shall be as follows:

The exclusive purpose of this Fellowship is *The discovery of Improvements in the Chemistry of Laundering,* to the furtherance of which the holder of this Fellowship shall give his whole time and attention.

The Fellow shall be appointed by the Chancellor of the University, the Director of the Chemical Department and the Professor of Industrial Chemistry; he shall be a member of the University and shall pay all regular fees, including laboratory fees; he shall work under the advice and direction of the Professor of Industrial Chemistry, and he shall forward periodically, through the Professor of Industrial Chemistry, reports of the progress of his work to *The A. B. Company.*

For the support of this Fellowship, which shall extend through a period of *Two Years* from the date of appointment of the Fellow, *The A. B. Company* agree to pay *Five Hun-*

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* The written parts of the agreement are printed in italics.

dred Dollars per year, payable annually to the University on the *First of March.* This sum shall be paid by the University in monthly instalments to the holder of the Fellowship.

Any and all discoveries made by the Fellow during the tenure of his Fellowship shall become the property of *The A. B. Company* subject, however, to the payment by them to the Fellow of one-tenth of the net proceeds arising from such discoveries, it being understood that the Fellow shall be regarded as the inventor. At or before the expiration of the Fellowship, the business services of the Fellow may be secured by *The A. B. Company* for a term of *Three Years* on condition that the terms of such services are satisfactory to both parties at interest.

It is also understood and agreed that, on the expiration of the Fellowship, the holder thereof shall have completed a comprehensive monograph on *The Chemistry of Laundering* containing both what he and others have been able to discover. A copy of this monograph shall be forwarded to *The A. B. Company,* and a copy shall be signed and placed in the archives of the University until the expiration of three years from that date, when the University shall be at liberty to publish it for the use and benefit of the people.

It will be seen that this Fellowship affects three different parties: The Industry, the University standing for the people, and the Fellow appointed.

As for the Industry: The A. B. Company is concerned with the manufacture of launderers' materials. This company believes that the laundry business, while along mechanical lines it may be considered to have reached a condition of what might be called terminal perfection, along chemical lines is conducted on a basis of almost mediæval ignorance; that it has been developed upon the slenderest knowledge of the material of cotton and linen textiles; and that it is practised with a joyous disregard of the whole body of modern chemical knowledge. It believes that the chemical methods of the present-day laundry cannot only be changed, but radically changed; and it also believes that this change must be initiated from the outside — that its own chemists cannot solve its problems.

Consequently, the company has appreciated the opportunity of founding in this progressive University in the West a Temporary Fellowship for the solution of this one specific problem, for it sees that in combining the "inside" knowledge and big facilities of its factories with the special knowledge and trained action of the University and its Fellow, there lies a sane, practical chance of a happy solution. It is willing to offer the Fellow appointed not merely the yearly $500 which constitutes the stipend of his Fellowship, but, in addition, one-tenth of the value of all that he can discover, as well as, ultimately, a permanent position with the company on a mutually satisfactory basis—one-tenth, because a tax of a tithe upon a successful innovation in factory practice can never be burdensome, and a permanent position, because, if the Fellow succeeds, the company must have him, and, whether or not, it always needs "good men."

The University, listening, as becomes a State University, with its ear to the ground, and unlike those institutions that are concerned only with their own self-perpetuation, has heard the murmurs of the people. Indeed, who has not? For, as a matter known by everybody and freely yet regretfully acknowledged by laundry men themselves, the course of the shirt to the laundry is one of swift and progressive disintegration. Since the people of this country pay a laundry bill of nearly twenty-five million dollars a week, and, in addition, vastly more than this in replacing fabrics which the laundry destroys, the solution of this problem is of unquestionable importance to their welfare. The University, therefore, in behalf of the people, is willing to extend its advice and facilities to the industry concerned, but—and in this "but" there lies the whole function of the University—it insists that the knowledge obtained within its gates should in a reasonable time become the common property of man. This is conserved by the agreement that, before the expiration of the Fellowship, the Fellow shall have completed a comprehensive monograph fairly exploiting all that he and others before him have succeeded in discovering. This monograph, after giving the company three years' advantage, the University will publish. This does not mean that the Fellow and the company are prohibited from taking out, at any time, patents on discoveries with industrial likelihood; but patents genally convey but a small proportion of the knowledge requisite for working them; and so, through this monograph, the means of using these patents after their expiration, and of improving them before their expiration, will be conserved to the people.

As for the Fellow appointed to the task, he pits his youth and strength and training and creative ability against a problem which the company, with its inner knowledge of the conditions of the business, believes to be solvable. He is eager enough to attempt his devoir, because, while guaranteed a sum adequate to support him and sufficient time to make his achievement, he is guaranteed also a fair share of the spoils should he succeed. It is a game in which he has a reasonable chance of winning anything from zero to a million, and he is assured of the “square deal.” What more can be desired by a young man at the threshold of his activity, even if it means that he must leave the “nook merely monastic” of a professor in embryo for a life of industrial alarums and strenuous war? In addition, he has in the monograph which he writes the opportunity of proving himself a supreme authority in this limited but important field; he has, if he wins, an assured position by which he may take a notable part in what in these days is the preferred work of the world, the doing of real things, the turning of knowledge to useful ends; and then, too, his work may all be carried on in strictest accordance with the science in which he has been bred.

Finally, a rereading of this agreement will show that it is essentially one of trust. The University stands sponsor to this arrangement, because, in any particular instance in which the foundation of a Fellowship is accepted, it will first convince itself of the integrity of all concerned. For that reason, the foregoing agreement, for example, has been drawn in a broad and liberal spirit, and it thus stands to the young men in the University as a demonstration that opportunity waits not only upon training and ability, but, first and foremost, upon a reputation for absolute integrity.

Everywhere throughout America, wherever there is the smoke of a factory chimney, there are unsolved, exasperating, vitally important manufacturing problems — problems in glass, porcelain, starch, tanning, paints, drugs, meats, iron, oil, metallurgical products— problems wherever man deals with substance. It seems clear that these problems can best be answered by combining the practical knowledge and the large facilities of the factory with the new and special knowledge of the universities, and by making this combination through young men who will find therein success and opportunity.

A Temporary Industrial Fellowship does this: it affords a young man every incentive to lay his hands on the vast body of correlated knowledge called Science, and to make it subserve the practical needs of the human race.

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